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(54) Apparatus for embossing a flexible substrate with a pattern carried by an optically transparent compliant media

(57) An apparatus **200** for embossing a flexible substrate **101** with an optically transparent compliant media **70** is disclosed. The complaint media **70** includes an optically transparent imprint stamp **20t** with an imprint pattern **20q** therein. The flexible substrate **101** is coated with a photopolymer material **301**. The compliant media **70** can be connected with an optically transparent belt material **81** to form an embossing belt **100** or connected with an optically transparent cylinder **69** to from an embossing drum **90**. A coated side **101c** of the flexible substrate **101** is urged into contact with the imprint stamp **20t** and the imprint pattern **20q** is embossed in the photopolymer material **301** and an ultraviolet light L passing through the compliant media **70** contemporaneously cures the photopolymer material **301** during the embossing.

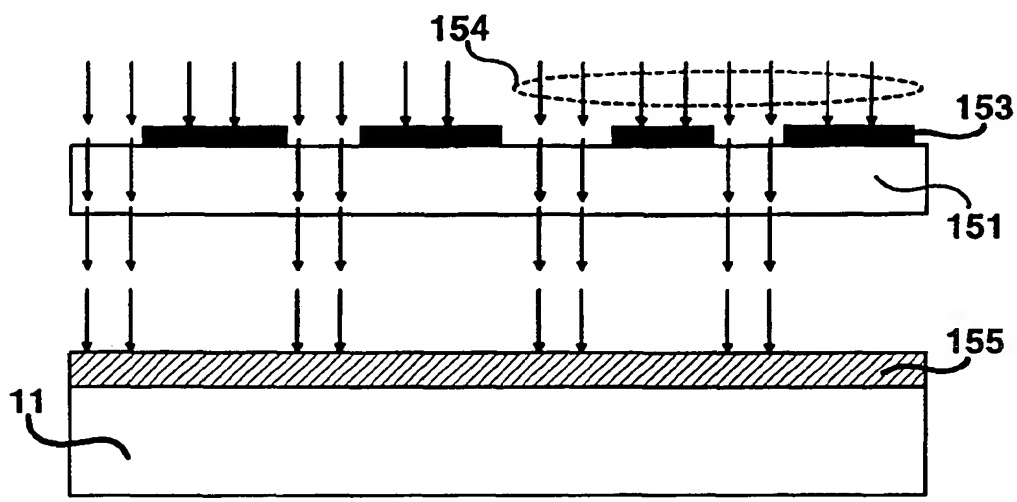

FIG. 1

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Description

FIELD OF THE INVENTION

[0001] The present invention relates generally to an apparatus for embossing a flexible substrate. More specifically, the present invention relates to an apparatus for embossing a photopolymer coated flexible substrate with an imprint pattern transferred from an imprint stamp carried by an optically transparent compliant media. The imprint stamp is irradiated through the compliant media with ultraviolet light contemporaneously with the embossing so that the transferred imprint pattern cures, hardens, and retains its shape.

BACKGROUND OF THE INVENTION

[0002] Current roll-to-roll soft lithography processes for embossing a photopolymer coated web include a process and apparatus used by Epigem Ltd., wherein a web material that is transparent to ultraviolet light is coated with a layer of photopolymer resist and the coated side of the web is brought into contact with an embossing shim that carries an imprint pattern. When the web separates from the embossing shim, the imprint pattern is embossed in (i.e. is replicated in) the layer of photopolymer resist. An ultraviolet light source irradiates the layer of photopolymer resist through the web and cures the embossed pattern so that the pattern hardens and retains its embossed shape. Because the web is transparent to the ultraviolet light, placement of the ultraviolet light source is not problematic and the embossing shim can be opaque to ultraviolet light and the irradiation can occur from the web side.

[0003] One disadvantage of the above apparatus is that if the web material and the embossing shim are opaque to ultraviolet light, then the irradiation will not be effective from the web side or the embossing shim side. Accordingly, if a roll-to-roll process requires the web material to be opaque to ultraviolet light, then the embossing shim must be optically transparent to the ultraviolet light so that the irradiation of the embossed pattern in the layer of photopolymer resist can occur from the embossing shim side.

[0004] In contrast, researchers at various universities (e.g. University of Texas at Austin, Step and Flash Imprint Lithography) have used quartz shims (templates) that are optically transparent to ultraviolet light. However, that process is a batch oriented wafer-based process that is not suitable for a roll-to-roll soft lithography process.

[0005] Consequently, there is an unmet need for an apparatus for implementing a roll-to-roll soft lithography process wherein an optically transparent compliant media that carries an imprint stamp, is used to emboss a pattern in a photopolymer coated on an opaque flexible substrate. There is also a need for an apparatus that allows the pattern embossed in the flexible substrate to be cured by ultraviolet light that irradiates the pattern through the compliant media and the imprint stamp.

SUMMARY OF THE INVENTION

[0006] Broadly, the present invention is embodied in an apparatus for embossing a flexible substrate with a pattern carried by an optically transparent compliant media. The compliant media includes an optically transparent imprint stamp that includes an imprint pattern. The compliant media can be connected with an optically transparent belt material or with an optically transparent cylinder.

[0007] The flexible substrate includes a coated side that is coated with a photopolymer material and the coated side is urged into contact with the compliant media so that the imprint pattern carried by the imprint stamp is embossed in the photopolymer material. An ultraviolet light source irradiates the photopolymer material with ultraviolet light that passes through the compliant media and the imprint stamp and impinges on the pattern embossed in the photopolymer material thereby curing the pattern. The curing of the pattern in the photopolymer material occurs contemporaneously with the embossing so that the pattern hardens and retains its shape.

[0008] One advantage of the apparatus of the present invention is that the irradiation occurs through the compliant media so that the flexible substrate can be opaque to ultraviolet light.

[0009] Another advantage of the present invention is that the ultraviolet light source can be placed inside or outside of the belt material the compliant media is connected with. If a cylinder is used, then the ultraviolet light source can be placed or inside of or outside of the cylinder the compliant media is connected with.

[0010] Other aspects and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

FIGS. 1 through **5** depict patterning and etching a master substrate to define an imprint pattern according to the present invention.

FIG. 6 depicts a release layer conformally deposited on an imprint pattern according to the present invention.

FIG. 7 depicts a silicon-based elastomer layer deposited over a release layer according to the present invention.

FIGS. 8 through 10 depict separating a silicon-

based elastomer layer from a release layer to form an imprint stamp according to the present invention.

FIG. 11 depicts applying a thin plastic film to a silicone rubber backing according to the present invention.

FIG. 12 depicts a coating of a thin plastic film with a photopolymer solution according to the present invention.

FIGS. 13 and **14** depict a spreading of a photopolymer solution to form a photopolymer layer over a thin plastic film according to the present invention.

FIG. 15 depicts a placing of a patterned side of an imprint stamp on a photopolymer layer according to the present invention.

FIG. 16 depicts curing a photopolymer layer according to the present invention.

FIG. 17 depicts removing an imprint stamp from a photopolymer layer according to the present invention.

FIG. 18 depicts a photopolymer shim formed in a photopolymer layer according to the present invention.

FIG.19 depicts a fluorocarbon coating deposited on a photopolymer shim according to the present invention.

FIG. 20 depicts a photopolymer shim attached to a support substrate according to the present invention.

FIG. 21 depicts a shim stock attached to a support substrate and a pre-heating of the support substrate according to the present invention.

FIGS. 22 and **23** depict coating and spreading a silicone-based elastomer material over of a photopolymer shim and a shim stock according to the present invention.

FIG. 24 depicts a heating of a support substrate according to the present invention.

FIGS. 25 through **27** depict applying a transfer adhesive to a compliant media according to the present invention.

FIG. 28 depicts separating a compliant media from a support substrate according to the present invention.

FIG. 29 is a top plan view and a cross-sectional view of an imprint pattern carried by a photopolymer shim according to the present invention.

FIG. 30 depicts a compliant assembly according to the present invention.

FIGS. 31a through **34b** depict attaching a compliant assembly to a cylinder according to the present invention.

FIGS. 35 through **37b** depict attaching a compliant assembly to a belt material according to the present invention.

FIGS. 38 and **39** are schematics depicting an apparatus for embossing a flexible substrate using an optically transparent compliant media connected with an optically transparent belt material according to the present invention.

FIGS. 40 and **41** are schematics that depict an apparatus for embossing a flexible substrate using an optically transparent compliant media connected with an optically transparent cylinder according to the present invention.

FIG. 42 is a schematic of a coating unit according to the present invention.

FIG. 43 is a schematic of a coating unit that includes a Gravure type coater according to the present invention.

FIG. 44 is a schematic of a coating unit that includes a Slotdie coater according to the present invention.

FIG. 45 is a cross-sectional view depicting an irradiation of a photopolymer material through an optically transparent belt material, compliant media, and imprint stamp according to the present invention.

FIG. 46 is a cross-sectional view depicting an irradiation of a photopolymer material through an optically transparent cylinder, compliant media, and imprint stamp according to the present invention.

FIG. 47 is a top plan view and a cross-sectional view of a replicate pattern embossed in a photopolymer material according to the present invention.

DETAILED DESCRIPTION

[0012] In the following detailed description and in the several figures of the drawings, like elements are identified with like reference numerals.

[0013] In **FIGS. 38** through **47**, an embossing appa-

ratus that includes an optically transparent embossing belt or an optically transparent embossing drum is illustrated.

[0014] In **FIGS.1** through **37b,** a method of making an optically transparent complaint media that can be connected with an optically transparent belt material or an optically transparent cylinder is illustrated.

[0015] As shown in the drawings for purpose of illustration, the present invention is embodied in an embossing apparatus. In one embodiment of the present invention, the embossing apparatus includes a flexible substrate with a coated side and a base side, a coating unit for depositing a photopolymer material having a first thickness on the coated side of the flexible substrate, and an embossing belt including an optically transparent belt material and an optically transparent complaint media that is connected with the belt material. The compliant media includes an optically transparent imprint stamp with an imprint pattern that will be embossed in the photopolymer material on the coated side to form a replicate pattern in the photopolymer material. A plurality of transport rollers are connected with the belt material and are operative to support the embossing belt.

[0016] A drive unit imparts a drive motion to the embossing belt and the flexible substrate so that the coated side is brought into contact with the imprint stamp and the imprint pattern is replicated in the photopolymer material. A backing drum is wrapped by a portion of the base side of the flexible substrate and by a portion of the compliant media so that a tension is imparted in the embossing belt and that tension generates a pressure between the flexible substrate and the embossing belt.

[0017] The drive motion is operative to transport the base side of the flexible substrate over the backing drum and to urge the imprint stamp and the coated side into contact with each other so that the imprint pattern is embossed in the photopolymer material to form the replicate pattern in the photopolymer material. An ultraviolet light source irradiates the replicate pattern with ultraviolet light that passes through the belt material, the compliant media, and the imprint stamp. The irradiation of the replicate pattern occurs contemporaneously with the embossing of the replicate pattern so that the replicate pattern cures, hardens, and retains its shape.

[0018] In an alternative embodiment of the present invention, the embossing apparatus includes a flexible substrate with a coated side and a base side, a coating unit for depositing a photopolymer material having a first thickness on the coated side of the flexible substrate, and an embossing drum that includes an optically transparent cylinder and an optically transparent complaint media that is connected with the cylinder. The compliant media includes an optically transparent imprint stamp with an imprint pattern that will be embossed in the photopolymer material on the coated side to form a replicate pattern in the photopolymer material.

[0019] A drive unit imparts a drive motion to the embossing drum and the flexible substrate so that the coated side is brought into contact with the imprint stamp and the imprint pattern is replicated in the photopolymer material. A plurality of transport rollers are connected with the base side and are operative to conformally wrap the coated side over a portion of the embossing drum so that the embossing drum imparts a tension in the flexible substrate and that tension generates a pressure between the flexible substrate and the embossing drum.

[0020] The drive motion is operative to transport the coated side over the embossing drum and to urge the imprint stamp and the coated side into contact with each other so that the imprint pattern is embossed in the photopolymer material to form the replicate pattern in the photopolymer material. An ultraviolet light source irradiates the replicate pattern with ultraviolet light that passes through the cylinder, the compliant media, and the imprint stamp. The irradiation of the replicate pattern occurs contemporaneously with the embossing of the replicate pattern so that the replicate pattern cures, hardens, and retains its shape.

[0021] In **FIG. 38,** an embossing apparatus **200** includes a flexible substrate **101** that includes a coated side **101c** and a base side **101b.** A coating unit **300** is operative to deposit a photopolymer material **301** (see **FIGS. 42, 43,** and **44)** on the coated side **101c.** The photopolymer material **301** has a first thickness $\mathbf{t_c}$. An embossing belt **100** includes an optically transparent belt material **81** and an optically transparent compliant media **70** that is connected with the belt material **81** (see **FIG. 45).** The complaint media **70** also includes an optically transparent imprint stamp **20t** that includes an imprint pattern **20q** (see **FIG. 29).** Because the imprint pattern **20q** is formed from the same material as the imprint stamp **20t,** the imprint pattern **20q** is also optically transparent. **FIG. 45** and **FIGS. 37a** and **37b** provide a more detailed view of the embossing belt **100** than is depicted in **FIGS. 38** and **39.**

[0022] A plurality of transport rollers **103** are connected with the belt material **81** and are operative to support the embossing belt **100.** A drive unit **110** imparts a drive motion $\mathbf{W_D}$ to the embossing belt **100** and the flexible substrate **101.** As will be described below, the drive unit **110** can be connected with the embossing apparatus **200** in a variety of ways to accomplish the drive motion $\mathbf{W_D}$.

[0023] A backing drum **105** is wrapped by a portion of the base side **101b** of the flexible substrate **101** and by a portion of the compliant media **70** so that a tension is imparted to the embossing belt **100** and the flexible substrate **101.** The tension generates a pressure between the flexible substrate 101 and the embossing belt 100. The pressure is operative to effectuate the embossing of the imprint stamp **20t** in the photopolymer material **301.** The drive motion $\mathbf{D_R}$ is operative to transport the base side **101b** over the backing drum **105** and to urge the imprint stamp **20t** and the coated side **101c** into contact with each other so that the imprint pattern **20q** is embossed in the photopolymer material **301** and forms

a replicate pattern **20u** (see **FIG. 47)** in the photopolymer material **301.**

[0024] An ultraviolet light source **99** irradiates the replicate pattern **20u** with an ultraviolet light **L** that passes through the belt material **81** and the imprint stamp **20t.** The irradiating of the replicate pattern **20u** occurs contemporaneously with the embossing of the replicate pattern **20u** so that the replicate pattern **20u** cures, hardens, and retains its shape. The replicate pattern **20u** includes a plurality of patterns **20v** therein that complement the patterns **20p** on the master substrate **11** (see **FIGS. 5** and **6**).

[0025] The ultraviolet light source **99** can include a reflector **99r** that focuses the ultraviolet light **L** at a point where the imprint stamp **20t** is urged into contact with the coated side **101c** so that the photopolymer material **301** is not cured by the ultraviolet light **L** before the imprint pattern **20q** is embossed in the photopolymer material **301.** In **FIG. 45,** the reflector **99r** (not shown) creates a curing window $\mathbf{C_W}$ that focuses the ultraviolet light **L** at an area where the replicate pattern **20u** will be embossed and almost simultaneously cured. The reflector **99r** is also operative to prevent a leakage of the ultraviolet light **L** that could potentially impinge on the photopolymer material **301** and cause it to cure before it is embossed by the imprint stamp **20t.**

[0026] One advantage of the present invention is that the embossing apparatus **200** is effective at embossing and curing the photopolymer material **301** when the flexible substrate **101** is opaque to the ultraviolet light **L** because the irradiation of the replicate pattern **20u** occurs through the embossing belt **100** as opposed to through the flexible substrate **101.** Accordingly, the embossing apparatus **200** of the present invention can be used to emboss and cure the photopolymer material **301** on an opaque flexible substrate **101** or on an optically transparent flexible substrate **101**. Because some application will require that the material for the flexible substrate **101** be an opaque material, the embossing apparatus **200** of the present invention allows for flexibility in the selection of materials for the flexible substrate **101**.

[0027] The ultraviolet light source **99** can be a UVA ultraviolet light source, preferably an industrial grade UVA light source as it is desirable to cure the replicate pattern **20u** in a very short period of time that is on the order of about 0.1 second to about 6.0 seconds. Preferably, the ultraviolet light **L** has a wavelength from about 300.0 nm to about 400.0 nm. Intensities for the ultraviolet light source **99** will also be application dependent; however, as an example, intensities in a range from about 200.0 mW/cm^{2}to about 1000.0 mW/cm^2 can be used. As another example, **Norland™** Optical Adhesives require about 0.2 Joules/cm^2 total energy to cure.

[0028] In that the irradiation of the photopolymer material **301** occurs through the embossing belt **100,** the ultraviolet light source **99** can have a position relative to the embossing belt **100** that includes a position inside the embossing belt **100** as depicted in **FIGS. 39** and **45** and a position outside of the embossing belt **100** as depicted in **FIGS. 38** and **45**. When the ultraviolet light source **99** is positioned outside of the embossing belt **100** as in **FIG. 38**, it may be necessary to take into account a slight attenuation in an intensity of the ultraviolet light **L** due to the ultraviolet light **L** passing through two layers of the embossing belt **100** as opposed to one layer when the ultraviolet light source **99** is positioned inside the embossing belt **100**. Accordingly, it may be necessary to use a higher intensity ultraviolet light source **99** when the ultraviolet light source **99** is positioned outside the embossing belt **100.**

[0029] In **FIG. 39,** three transport rollers **103** are used in order to create a space to accommodate the ultraviolet light source **99** on the inside of the embossing belt **100.** However, because the compliant media **70** can be made to any size, there are a variety of ways to accommodate the ultraviolet light source **99** on the inside of the embossing belt **100** including making the embossing belt **100** longer and making a diameter of the transport rollers **103** larger in order to create a large enough space to accommodate the ultraviolet light source **99**. Therefore, the embodiment of **FIG. 39** is just one example of how to accommodate the ultraviolet light source **99** on the inside of the embossing belt and other configurations are also possible and the present invention is not limited to the configuration illustrated in **FIG. 39.**

[0030] In **FIG. 42,** the coating unit **300** is operative to deposit the photopolymer material **301** on the coated side **101c** with the first thickness $\mathbf{t_c}$**.** Typically, the photopolymer material **301** is supplied in a liquid form **301L** prior to the depositing on the coated side **101c**. During the drive motion $\mathbf{W_D}$, it is important that a coating distance $\mathbf{D_c}$ between the coated side **101c** and the coating unit **300** be accurately maintained so that the first thickness $\mathbf{t_c}$ does not vary and the photopolymer material **301** is deposited as a smooth and uniform layer on the coated side **101c.** The photopolymer material **301** can include but is not limited to a **Norland™** Optical Adhesive that cures when exposed to ultraviolet light. Preferably, the photopolymer material will cure in a time from about 0.1 seconds to about 6.0 seconds. For example, a **Norland® NOA 83H** photopolymer can be used for the photopolymer material **301.** The photopolymer material 301 can also be a photo resist material.

[0031] Optionally, the embossing apparatus **200** can include a guide roller **109** that is operative to maintain the constant distance $\mathbf{D_c}$ between the coated side **101c** and the coating unit **300** so that the first thickness $\mathbf{t_c}$ of the photopolymer material **301** is accurately maintained. The guide roller **109** is particularly useful when a supply reel **107s** is used to carry and dispense the flexible substrate **101.** As the flexible substrate **101** is spooled off of the supply reel **107s,** its distance from the coating unit **300** can vary and will increase as a wound diameter of the flexible substrate **101** decreases as the flexible substrate **101** is wound off of the supply reel **107s**. Accordingly, the guide roller **109** controls the distance between

the coated side **101c** and the coating unit **300.**

[0032] The first thickness $\mathbf{t_c}$ of the photopolymer material **301** will be application dependent and the type of coating unit **300** will also be application dependent. The first thickness $\mathbf{t_c}$ is generally comparable to the typical feature height (see $\mathbf{h_0}$ in **FIG. 4**) in order to minimize embossing residue for subsequent etching of the embossed layer. For example, if the imprint stamps **20t** include imprint patterns **20q** that are of a nanometer scale (e.g. less than 1.0 μm and preferably less than 100.0 nm), then it is desirable to deposit a very thin layer of the photopolymer material **301.** Preferably, the first thickness $\mathbf{t_c}$ is in a range from about 0.05 μm to about 2.0 μm.

[0033] A coating technology capable of depositing a uniform and thin layer of the photopolymer material **301** and that can be used for the coating unit **300** includes but is not limited to a Gravure Coater, a **Micro Gravure™ Coater**, and a Slot Die Coater. For example, the above mentioned range of thicknesses for the first thickness $\mathbf{t_c}$ can be obtained using a **Yasui Setki™ Micro Gravure™ Coater**. The photopolymer material **301** can be thinned with a solvent, such as acetone, to achieve a thinner coating for the first thickness $\mathbf{t_c}$.

[0034] In **FIG. 43,** the coating unit **300** can be a Gravure Coater or a **Micro Gravure™ Coater.** A pair of rollers **303r** conformally wrap a portion of the coated side **101c** of the flexible substrate **101** over an engraved drum **303g** that rotates in a tub **303s** that contains a liquid photopolymer material **301 L**. The photopolymer material **301 L** is gathered on patterns on a surface of the drum **303g**. A doctor blade **303d** wipes off an excess of the photopolymer material **301 L** so that a thin and uniform layer is deposited on the coated side **101c**. Preferably, a Micro **Gravure™ Coater** is used as it has a drum **303g** with a smaller diameter than that of a Gravure Coater and is better suited to depositing ultra-thin layers of the photopolymer material **301.**

[0035] Alternatively, in **FIG. 44** a Slot Die Coater can be used to deposit the photopolymer material **301.** The liquid photopolymer material **301L** is supplied $\mathbf{S_f}$ under pressure to a die slot **301S** formed by a pair of die lips **301D.** The die lips **301D** are positioned above the flexible substrate **101** by a coating gap $\mathbf{t_G}$ that includes a thickness $\mathbf{t_s}$ of the flexible substrate **101.** As the coated side **101c** of the flexible substrate **101** passes under the die slot **301S**, the liquid photopolymer material **301L** coats the coated side **101c** to the first thickness $\mathbf{t_c}$.

[0036] The drive motion $\mathbf{t_c}$ can be accomplished using a variety of techniques that are well understood in the coating art and the mechanical art. As one example, in **FIG. 38,** a drive unit **110** mechanically communicates with a takeup reel **107r** that is operative to collect the flexible substrate **101** after it has been embossed and cured as described above.

[0037] The takeup reel **107r** can be connected with the drive unit **110** using a drive belt **110b** that imparts a rotation $\mathbf{D_R}$ to the takeup reel **107r** which in tum collects the flexible substrate **101** on the takeup reel **107r** and imparts the drive motion $\mathbf{W_D}$ to the flexible substrate **101** and the embossing belt **100.** Although a drive belt **110b** is depicted, any means for mechanically communicating a drive force including gears, direct drive, pulleys, shafts, and the like can be used. The drive unit **110** can be an electric motor, for example.

[0038] One or more of the drive units **110** may be used to impart the drive motion $\mathbf{W_D}$ and those drive units **110** can be connected with one or more of the components of the embossing apparatus **200,** such as one or more of the transport rollers **103** so that the drive unit **110** rotates the transport roller **103** which in turn imparts the drive motion $\mathbf{W_D}$ to the flexible substrate **101** and the embossing belt **100.**

[0039] The compliant media **70** can be made from an optically transparent silicone-based elastomer material that is laminated to an optically transparent transfer adhesive layer as will be described below in reference to **FIGS.1** through **37b.** Suitable materials for the silicone-based elastomer material (see reference numeral **44** in **FIG. 22**) include but are not limited to Polydimethyl Siloxane (**PDMS**), **DOW CORNING®** silicone-based conformal coatings including **SYLGARD 182®** silicone elastomer, **SYLGARD 183®** silicone elastomer, **SYLGARD 184®** silicone elastomer, and **SYLGARD 186®** silicone elastomer.

[0040] A suitable optically transparent material for the transfer adhesive layer (see reference numeral **51** in **FIG. 27**) includes but is not limited to an **Adhesives Research, Inc.® ARclear® DEV-8932** optically clear silicone adhesive. For instance, a 25.0 μm thick sheet (i.e the seventh thickness $\mathbf{t_7}$ = 25.0 μm) of **ARclear® DEV-8932** can be used for the transfer adhesive layer **51.**

[0041] The belt material **81** can be an optically transparent material so that light **L** can pass though the belt material **81,** the compliant media **70,** and the imprint stamp **20t.** Suitable optically transparent materials for the belt material **81** include but are not limited to a Polyester film and **Mylar®.** Although a thickness of the belt material **81** will vary based on the application, a suitable range for the thickness of the belt material **81** that will result in a flexible belt when connected with the compliant media **70** is from about 50.0 μm to about 150.0 μm

[0042] In an alternative embodiment of the present invention, as illustrated in **FIGS. 40, 41,** and **46,** the embossing apparatus **200** includes an embossing drum instead of the aforementioned embossing belt **100**. The embossing apparatus **200** includes the flexible substrate **101**, the coating unit **300**, and an embossing drum **90** that includes an optically transparent cylinder **69** and the optically transparent complaint media **70** that is connected with the cylinder **69**. As described above, the complaint media **70** includes the optically transparent imprint stamp **20t** with the imprint pattern **20q** therein. **FIG. 46** and FIGS. **32** through **34b** provide a more detailed view of the embossing drum **90** than is depicted in **FIGS. 40** and **41**.

[0043] Also as described above, a drive unit **110** imparts a drive motion $\mathbf{W_D}$ to the embossing drum **90** and the flexible substrate **101.** The embossing apparatus **200** can include the above mentioned guide roller **109** for maintaining the constant distance $\mathbf{D_c}$, the supply reel **107s,** and the takeup reel **107t.** The drive unit **110** may drive the takeup reel **107t** and/or one or more of the transport rollers **103.** Aternativey, the embossing drum **90** may be driven by the drive unit **110;** however, care should be taken to avoid slippage between the compliant media **70** and the flexible substrate **101.**

[0044] A plurality of the transport rollers **103** are connected with the base side **101b** of the flexible substrate **101** and are operative to conformally wrap the coated side **101c** over a portion of the embossing drum **90** so that the embossing drum **90** imparts a tension in the flexible substrate **101** and that tension generates a pressure between the flexible substrate **101** and the embossing drum **90.** The pressure is operative to effectuate the embossing of the imprint stamp **20t** in the photopolymer material **301.**

[0045] The drive motion $\mathbf{W_D}$ transports the coated side **101c** over the embossing drum **90** and urges the imprint stamp **20t** into contact with the coated side **101c** so that the imprint pattern **20q** is embossed in the photopolymer material **301** to form the replicate pattern **20u** in the photopolymer material **301.** In **FIG. 46,** the compliant media **70** forms an outer surface of the embossing drum **90** so that the coated side **101c** comes into contact with the compliant media **70** and the imprint stamp **20t** as the flexible substrate **101** is transported over the wrapped portion of the embossing drum **90.**

[0046] The ultraviolet light source **99** irradiates the replicate pattern **20u** with the ultraviolet light **L** that passes through the cylinder **69** and the imprint stamp **20t.** The irradiating of the replicate pattern **20u** occurs contemporaneously with the embossing of the replicate pattern **20u.**

[0047] As previously described, the flexible substrate **101** can be opaque to the ultraviolet light **L.** In **FIGS. 40, 41,** and **46,** the ultraviolet light source **99** can be positioned inside the embossing drum **90** or outside the embossing drum **90.** It may be necessary to increase an intensity of the ultraviolet light source **99** if the ultraviolet light source **99** is positioned outside of the embossing drum **90** because the ultraviolet light **L** must pass through two layers of the cylinder **69** and the compliant media **70** and some attenuation of the ultraviolet light **L** may occur.

[0048] The ultraviolet light source **99** can include the reflector **99r** as described above and the reflector **99r** can create the curing window $\mathbf{C_w}$ (see **FIG. 46).** The ultraviolet light source **99** can be a UVA light source and the ultraviolet light **L** can have a wavelength from about 300.0 nm to about 400.0 nm.

[0049] The same materials as described above for the embossing belt 100 can be used for the embossing drum 90; however, the cylinder 69 can be an optically transparent material including but not limited to a glass, a plastic, and quartz.

[0050] The aforementioned Gravure Coater, **Micro Gravure™ Coater**, or Slot Die Coater can be used for the coating unit **300** and the first thickness $\mathbf{t_c}$ of the photopolymer material **301** can be in a range from about 0.5 µm to about 1.0 µm.

[0051] The embossing belt **100** and the embossing drum **90** can be made using a method described below in reference to **FIGS. 1** through **37b.**

[0052] In **FIGS. 1** through **4,** a master substrate **11** is patterned and then etched to form an imprint pattern **20** therein. In **FIG. 1,** the master substrate **11** is coated with a material **155** that will serve as an etch mask. The material **155** can be a photoresist material that is commonly used in the microelectronics art. A mask **151** that carries a pattern **153** to be formed in the master substrate **11** is illuminated with light **154** which exposes the material **155** with the pattern **153.**

[0053] In **FIG. 2,** the material **155** is developed to remove those portions of the material **155** that were exposed to the light **154.** In **FIGS. 2** and **3,** the master substrate **11** is etched with an etch material to remove those portions of the master substrate **11** that are not covered with the material **155.** As a result, in **FIG. 3,** a plurality of imprint patterns **20p** are formed in the master substrate **11.** In **FIG. 4,** the imprint patterns **20p** define an imprint stamp **20** on the master substrate **11.**

[0054] The imprint stamp **20** can include imprint patterns **20p** that vary in all three dimensions of width, length, and height. In the cross-sectional view of **FIG. 4** and the top plan view of **FIG. 5,** the imprint patterns **20p** vary in a width dimension $\mathbf{d_0}$, a height dimension $\mathbf{h_0}$, and a length dimension $\mathbf{L_0}$. The actual dimensions of the imprint patterns **20p** will be application dependent and will depend to a large extent on the lithography process used for the patterning the material **155.** For example, if a state-of-the-art microelectronics lithography process is used, then the dimensions $(\mathbf{d_0}, \mathbf{h_0}, \mathbf{L_0})$ can be of a sub-micrometer scale, that is, less than 1.0 µm. For instance, the imprint patterns **20p** can be nano-imprint patterns that can have dimensions $(\mathbf{d_0}, \mathbf{h_0}, \mathbf{L_0})$ of 100.0 nm or less. Accordingly, the imprint stamp **20** would be a nano-imprint stamp with imprint patterns **20p** that have nanometer-size dimensions $(\mathbf{d_0}, \mathbf{h_0}, \mathbf{L_0})$.

[0055] Lithography processes that are well understood in the microelectronics art can be used to pattern and etch the master substrate **11.** For example, a photolithography process using a photoresist for the material **155** and an etch process such as reactive ion etching (RIE) can be used to form the imprint stamp **20** in the master substrate **11.**

[0056] Suitable materials for the master substrate **11** include but are not limited to a silicon (Si) substrate and a silicon (Si) wafer. In **FIG. 5,** the master substrate **11** is a silicon wafer with a wafer flat **11F**. Four of the imprint stamps **20** are formed in the master substrate **11**. The silicon wafer can be any size. For example a 4.0 inch

silicon wafer was used as the master substrate **11** for four of the imprint stamps **20.** Larger diameter silicon wafers (e.g. 8 inch or 12 inch) can be used to provide a larger surface area for more of the imprint stamps **20** or for larger imprint stamps **20.** Although the imprint patterns **20p** appear to be identical in **FIG. 5**, the imprint stamps **20** can include imprint patterns **20p** that vary (i. e are not identical) among the imprint stamps **20.**

[0057] In **FIG. 6**, a release layer **13** is deposited over the imprint patterns **20p.** The release layer **13** includes a first thickness $\mathbf{t_1}$ that is operative to conformally coat the imprint patterns **20p** such that the first thickness $\mathbf{t_1}$ is substantially equally thick on the vertical and the horizontal surfaces of the imprint patterns **20p.** Suitable materials for the release layer **13** include but are not limited to a fluorocarbon material. As an example, the fluorocarbon material for the release layer **13** can be deposited using a plasma deposition of a trifluoromethane **(CHF_3)** gas for about 5.0 minutes.

[0058] The first thickness $\mathbf{t_1}$ will be application dependent; however, as will be discussed below, the release layer **13** is operative to provide a non-stick surface upon which to apply a silicone-based elastomer material that will later be released from the release layer **13**. Therefore, the release layer **13** can be a very thin layer having a first thickness t, that is from about 50.0 nm to about 150.0 nm thick.

[0059] In **FIG. 7**, a silicone-based elastomer layer **15** is deposited over the release layer **13** to a first depth $\mathbf{d_1}$ that completely covers the imprint patterns **20p.** To obtain a uniform thickness for the silicone-based elastomer layer **15,** the master substrate **11** should be substantially level. This can be accomplished by placing the master substratel **11** on a level surface or a level vacuum chuck prior to depositing the silicone-based elastomer layer **15,** for example.

[0060] The silicone-based elastomer layer **15** is then cured by heating H the master substrate **11**. The curing can be accomplished by baking the master substrate 11 at a predetermined temperature for a predetermined amount of time. The actual time and temperature will be application dependent and will also depend on the type of material used for the silicone-based elastomer layer **15**. Suitable materials for the silicone-based elastomer layer **15** include but are not limited to Polydimethyl Siloxane **(PDMS), DOW CORNING®** silicone-based conformal coatings including **SYLGARD® 182** silicone elastomer, **SYLGARD® 183** silicone elastomer, **SYLGARD® 184** silicone elastomer, and **SYLGARD® 186** silicone elastomer.

[0061] The first depth $\mathbf{d_1}$ of the silicone-based elastomer layer **15** can be application dependent. However, in a preferred embodiment, the first depth $\mathbf{d_1}$ of the silicone-based elastomer layer **15** is from about 0.5 mm to about 1.5 mm. For **PDMS** or the **DOW CORNING® SYLGARD®** silicone-based elastomers, the curing of the silicone-based elastomer layer **15** can be accomplished by baking the master substrate **11** in an oven or the like. The predetermined temperature and the predetermined amount of time for the curing can be for about 4.0 hours at a temperature of about 100.0 °C.

[0062] In an alternative embodiment, also illustrated in **FIG. 6**, prior to the above mentioned curing step, a cover layer **16** having a second thickness $\mathbf{t_2}$ is applied over the already deposited silicone-based elastomer layer **15.** Preferably, the cover layer **16** is a Polyester film and the second thickness $\mathbf{t_2}$ is from about 50.0 μm to about 150.0 μm. The cover layer **16** may be used to planarize any surface anomalies in the silicone-based elastomer layer **15** that cause deviations from a substantially planar surface **15s** of the silicone-based elastomer layer **15.**

[0063] After the curing step, a complementary image of the imprint patterns **20p** are replicated **20r** in the silicone-based elastomer layer **15** such that an imprint stamp **20a** is formed in the silicone-based elastomer layer **15** (see **FIGS. 8** through **10**).

[0064] In **FIG. 7**, after the curing step, the silicone-based elastomer layer **15** is released from the release layer **13.** A tip of a pair of tweezers or an edge of a knife or razor, such as an **X-Acto®** Knife, can be used to separate the silicone-based elastomer layer **15** from the release layer **13** as depicted by a knife edge **K** and a dashed arrow inserted between the silicone-based elastomer layer **15** and the release layer **13.** The silicone-based elastomer layer **15** can then be lifted off of the release layer **13** by grabbing an edge of the silicone-based elastomer layer **15** and peeling off (see dashed arrow **P**) the silicone-based elastomer layer **15** from the release layer **13.** If the above mentioned cover layer **16** is used, then the cover layer **16** is removed from the silicone-based elastomer layer **15** before the silicone-based elastomer layer **15** is released from the release layer **13.**

[0065] In **FIGS. 8, 9,** and **10,** the imprint stamp **20a** is removed from an excess portion of the silicone-based elastomer layer **15** that surrounds the imprint stamp **20a.** If the above mentioned cover layer **16** is used, then the imprint stamp **20a** is removed from an excess portion of the silicone-based elastomer layer **15** and the cover layer **16** that surround the imprint stamp **20a.**

[0066] In either case, the imprint stamp **20a** can be removed from the excess portion by placing the silicone-based elastomer layer **15** on a substantially flat substrate **21** and then cutting **C** around a perimeter (see dashed lines in **FIGS. 8** and **9)** of the imprint stamp **20a** to release the excess portions of the silicone-based elastomer layer **15** or the silicone-based elastomer layer **15** and the cover layer **16** from the imprint stamp **20a.** A knife, razor, die, or the like can be used to accomplish the cutting as depicted by a knife **K** in **FIG. 9**. After the imprint stamp **20a** has been released, the excess portions (**15**, or **15** and **16**) can be peeled off of the substantially flat substrate **21** so that the imprint stamp **20a** is no longer connected with the excess portions (see FIG. **10**). The substantially flat substrate **21** can be a

material including but not limited to a glass, a metal, a plastic, and quartz. For example, the substantially flat substrate **21** can be a glass plate.

[0067] Optionally, the above mentioned steps may be repeated as necessary to produce additional imprint stamps **20a** using the master substrate **11.** One advantage of the method of the present invention is that the master substrate **11** is not damaged by the aforementioned process steps. Consequently, the same master substrate **11** can be repeatedly used to produce several imprint stamps **20a.** Therefore, the cost of patterning and etching the master substrate **11** and depositing the release layer **13** can be amortized over several imprint stamps **20a.**

[0068] Another advantage of the method of the present invention is that the master substrate **11** need not be cleaned after each use in order to remove contaminants, such as dust particles, because the silicone-based elastomer layer **15** flows around the particles and entrains them. Consequently, the master substrate **11** is self-cleaning because the particles are removed with the silicone-based elastomer layer **15.**

[0069] In **FIG. 11,** a flat and thin plastic film **33** having a third thickness $\mathbf{t_3}$ is placed on a flat and compliant silicone rubber backing **31** having a fourth thickness $\mathbf{t_4}$. Suitable materials for the thin plastic film **33** include but are not limited to a Polymide and a Polyester **(PET,** Polyethylene Terephthalate). The third thickness $\mathbf{t_3}$ and the fourth thickness $\mathbf{t_4}$ will be application dependent. Preferably, the third thickness $\mathbf{t_3}$ of the thin plastic film **33** is from about 40.0 μm to about 100.0 μm and the fourth thickness $\mathbf{t_4}$ of the silicone rubber backing **31** is from about 0.125 inches to about 0.25 inches. The fourth thickness $\mathbf{t_4}$ of the silicone rubber backing **31** should be selected to ensure the silicone rubber backing **31** is complaint (i.e. not stiff).

[0070] In **FIG. 12**, a surface **33s** of the thin plastic film **33** is coated with a photopolymer solution **35**. The photopolymer solution 35 can include but is not limited to a mixture of about 50% of a photopolymer material and about 50% acetone. As will be describe below, the acetone will evaporate leaving a substantially photopolymer layer on the surface **33s** of the thin plastic film **33.** The photopolymer material can include but is not limited to a **Norland™** Optical Adhesive that cures when exposed to ultraviolet light. Preferably, the photopolymer material will cure in a time from about 5.0 seconds to about 60.0 seconds. For example, a **Norland® NOA 83H** photopolymer can be used for the photopolymer solution **35.**

[0071] In **FIGS. 13** and **14,** the photopolymer solution **35** is spread over the surface **33s** of the thin plastic film **33** to form a photopolymer layer **35** having a fifth thickness $\mathbf{t_5}$. Preferably, the spreading of the photopolymer solution **35** is accomplished using a Mayer bar $\mathbf{M_1}$ that is wound with a wire $\mathbf{W_1}$ having a first diameter. The Mayer bar $\mathbf{M_1}$ slides **S** over the surface **33s** and meters the photopolymer solution **35** so that the photopolymer layer **35** having a fifth thickness $\mathbf{t_5}$ is formed. Any acetone in the photopolymer solution **35** substantially evaporates during the spreading process. As a result, the photopolymer layer **35** comprises substantially a photopolymer material as described above. Preferably, the fifth thickness $\mathbf{t_5}$ of the photopolymer layer **35** is from about 5.0 μm to about 10.0 μm. The first diameter of the wire $\mathbf{W_1}$ will be application dependent. Preferably, the first diameter of the wire $\mathbf{W_1}$ is from about 50.0 μm micrometers to about 100.0 μm.

[0072] In **FIG. 15,** a patterned surface **21a** of the imprint stamp **20a** is placed on the photopolymer layer **35.** Placing the imprint stamp **20a** on the photopolymer layer **35** can include placing an edge **e1** of the imprint stamp **20a** in contact with the photopolymer layer **35** and holding the edge **e1** down while progressively lowering see arrows **L1** and **d**) a remainder of the patterned surface **21a** into contact with the photopolymer layer **35**. A pair of tweezers or a suction wand can be used to grasp an edge **e2** to accomplish the lowering and to hold the edge **e1** down. Alternatively, a rubber roller or the like can be used in conjunction with the progressive lowering to bring the patterned surface **21a** into contact with the photopolymer layer **35.**

[0073] One advantage to the progressive lowering is that air entrapped between the photopolymer layer **35** and the patterned surface **20r** is displaced so that air bubbles that can cause defects are not trapped between the photopolymer layer **35** and the patterned surface **20r.**

[0074] Another advantage of the method of the present invention is that once the imprint stamp **20a** has been placed on the photopolymer layer **35,** the imprint stamp **20a** can be floated (see dashed arrow **F**) over a surface **35s** of the photopolymer layer **35** to position the imprint stamp **20a** at a predetermined location on the photopolymer layer **35**. The floating **F** can be done manually using a tweezer or suction wand, or the floating **F** can be automated and a precision mechanical device, such as a robotic end effector, can be used to precisely position the imprint stamp **20a**.

[0075] In **FIG. 16,** the photopolymer layer 35 is cured to fix a position of the imprint stamp **20a** on the photopolymer layer **35** and to transfer an image of the imprint pattern **20r** to the photopolymer layer **35.** The photopolymer layer **35** is cured by irradiating the photopolymer layer **35** with an ultraviolet light UV of a predetermined intensity for a first time period. The photopolymer layer **35** hardens as it cures and an the image of the imprint pattern **20r** that is transferred into the photopolymer layer **35** also hardens and is fixed in the photopolymer layer **35** as an imprint pattern **20s.**

[0076] The ultraviolet light **UV** can have a wavelength that includes but is not limited a range from about 300.0 nm to about 400.0 nm. The predetermined intensity of the ultraviolet light **UV** can include but is not limited to an intensity of about 150 mW/cm^2. The first time period can include but is not limited to a time period from about

5.0 seconds to about 60.0 seconds. For example, the ultraviolet light **UV** can be from a UVA ultraviolet light source.

[0077] Yet another advantage of the method of the present invention is that the imprint stamps **20a** that are used to pattern the photopolymer layer **35** can have a thickness (see $\mathbf{t_A}$ and $\mathbf{t_B}$ in **FIG. 16)** that can vary and those variations in thickness will not effect the accuracy of the transfer of the imprint pattern **20r** to imprint pattern **20s** of the photopolymer layer **35.** The variations in thickness **(**$\mathbf{t_A}$ and $\mathbf{t_B}$**)** can be due to variations in the process used to make the imprint stamps **20a,** variations in the first depth $\mathbf{d_1}$ of **FIG. 7,** or the use of different master substrates **11** to make different imprint stamps **20** with different imprint patterns **20p.**

[0078] After the curing step, in **FIGS. 17** and **18,** the imprint stamps **20a** are removed **P** from the photopolymer layer **35** so that the image of the imprint pattern **20r** defines a photopolymer shim **36** with the imprint pattern **20s** fixed therein. The imprint stamps **20a** can be removed **P** using a pair of tweezers or the like to grab an edge **(e1** or **e2)** and then lift the imprint stamps **20a** from the photopolymer layer **35** (see dashed arrow **P**).

[0079] In **FIG. 19,** the photopolymer shim **36** is post-cured by heating the photopolymer shim **36.** The post-curing of the photopolymer shim **36** can include but is not limited to a time of about 1.0 hour at a temperature of about 100 °C. Optionally, afer the post-curing step, the photopolymer shim **36** can be rinsed with an acetone solution to remove chemical species which might inhibit curing of a silicone based elastomer material such as **PDMS** or the above mentioned **SYLGARD®** silicone-based elastomers. The post-curing of the photopolymer shim **36** drives off cure-inhibiting species and improves an adhesion of the photopolymer shim **36** to the thin plastic film **33.**

[0080] In **FIG. 19,** after the post-curing of the photopolymer shim **36,** a coating of a fluorocarbon material **37** having a sixth thickness $\mathbf{t_6}$ is deposited on the photopolymer shim **36.** The sixth thickness $\mathbf{t_6}$ can include but is not limited to a thickness from about 50.0 nm to about 150.0 nm. As an example, the fluorocarbon material **37** can be deposited using a plasma deposition of a trifluoromethane **(**$\mathbf{CHF_3}$**)** gas for about 5.0 minutes.

[0081] Also in **FIG. 19,** after the deposition of the fluorocarbon material **37**, a tweezer or a knife edge can be inserted between the thin plastic film **33** and the silicone rubber backing **31** and the thin plastic film **33** can be pulled off of the silicone rubber backing **31** as shown by the dashed arrow **P**. Hereinafter, the combination of the photopolymer shim **36** and the thin plastic film **33** will be referred to as the photopolymer shim **36** unless otherwise noted.

[0082] In **FIG. 20,** after the thin plastic film **33** is separated, the photopolymer shim **36** is attached to a support substrate **41.** The photopolymer shim **36** can be connected with the support substrate **41** by laying the photopolymer shim **36** on the support substrate **41** and fastening an end of the photopolymer shim **36** to the support substrate **41** using an adhesive. For example, a high temperature adhesive tape **T** can be used. The support substrate **41** can be made from a material including but not limited to a glass and quartz.

[0083] In **FIGS. 21** and **22,** a shim stock **43** having a first height $\mathbf{h_1}$ is attached to the support substrate **41.** The shim stock **43** can be connected with the support substrate **41** using an adhesive such as the above mentioned high temperature adhesive tape **T,** for example. The shim stock **43** is positioned adjacent to the photopolymer shim **36** and is spaced apart from the photopolymer shim **36** by a first distance $\mathbf{D_1}$ so that there is a space between the shim stock **43** and the photopolymer shim **36** on a surface **41s** of the support substrate **41.** The first height $\mathbf{h_1}$ of the shim stock **43** should exceed a height $\mathbf{h_s}$ of the photopolymer shim **36** as depicted in **FIG. 22.** The first height $\mathbf{h_1}$ and the first distance $\mathbf{D_1}$ will be application dependent; however, the first height $\mathbf{h_1}$ can be in a range including but not limited to from about 0.5 mm to about 1.5 mm and the first distance $\mathbf{D_1}$ can be in a range including but not limited to from about 1.0 mm to about 2.0 mm. The shim stock **43** can be a material including but not limited to a metal, a glass, quartz, and stainless steel. For instance, the shim stock 43 can be a stainless steel shim stock and the first height $\mathbf{h_1}$ can be about 0.5 mm.

[0084] In **FIG. 21,** the support substrate **41** is preheated **H** to increase a temperature of the support substrate **41** in preparation for a coating of the shim stock **43** and the photopolymer shim **36** with a silicone-based elastomer material as will be discussed below. Preferably, the silicone-based elastomer material is not coated on a cold or on a room temperature (i.e. from about 18.0 °C to about 28.0 °C) support substrate **41.** The preheated temperature for the support substrate **41** will be application dependent and the temperature should not exceed a temperature limit of the photopolymer shim **36.** For example, the support substrate **41** can be preheated to a temperature of about 100 °C. A temperature of about 100 °C is below the temperature limits of most photopolymer materials.

[0085] In **FIGS. 22** and **23,** the photopolymer shim **36** and the shim stock **43** are coated with a compliant material **44** that completely covers the photopolymer shim **36** and the shim stock **43** (see **FIG. 22**). Suitable materials for the compliant material **44** include but are not limited to a silicone-based elastomer material and an amorphous fluoropolymer material.

[0086] Suitable silicone-based elastomer materials include but are not limited to Polydimethyl Siloxane **(PDMS), DOW CORNING®** silicone-based conformal coatings including **SYLGARD®** 182 silicone elastomer, **SYLGARD® 183** silicone elastomer, **SYLGARD® 184** silicone elastomer, and **SYLGARD® 186** silicone elastomer. Preferably, the **PDMS** is a mixture of about 10.0 parts of a base and about 1.5 parts of a curing agent. The base and the curing agent can be mixed by weight

or by volume as they have the same density.

[0087] A suitable material for the amorphous fluoropolymer material includes but is not limited to **TEFLON® AF**. For example, a **DuPont™ TEFLON® AF** can be used for the compliant material **44.** When the compliant material **44** comprises the amorphous fluoropolymer material, the above mentioned preheating step of **FIG. 21** is not required.

[0088] In **FIGS. 23** and **24,** the compliant material **44** is spread over the photopolymer shim **36** and the shim stock **43** to form a compliant media **45** that covers the photopolymer shim **36** and the shim stock **43** (see thicknesses $\mathbf{t_8}$ and $\mathbf{t_9}$ in **FIG. 24).** The imprint pattern **20s** in the photopolymer shim **36** is transferred to the compliant media **45** so that an imprint stamp **20t** is formed in the compliant media **45.**

[0089] Preferably, the spreading of the compliant material **44** is accomplished using a Mayer bar $\mathbf{M_2}$ that is wound with a wire $\mathbf{W_2}$ having a second diameter. The Mayer bar $\mathbf{M_2}$ slides **S** over the shim stock **43** and meters the compliant material **44** to form a smooth and uniformly thick compliant media **45.** The compliant material **44** will cover the shim stock **43** by a thickness $\mathbf{t_8}$ and will cover the photopolymer shim **36** by a thickness $\mathbf{t_9}$, where $\mathbf{t_9} >> \mathbf{t_8}$. The Mayer bar $\mathbf{M_2}$ is wound with a much coarser diameter of wire than the Mayer bar $\mathbf{M_1}$ that was discussed above. The second diameter of the wire $\mathbf{W_2}$ will be application dependent. Preferably, the second diameter of the wire $\mathbf{W_2}$ is from about 1.0 mm to about 3.0 mm. For example, a wire with a diameter of about 1.5 mm can be wound on the Mayer bar $\mathbf{M_2}$.

[0090] After the spreading, the support substrate **41** is heated **H**. The surface **41s** is operative to provide a surface for a portion **45c** of the compliant media **45** to adhere to during and after the heating step. The time and temperature for the heating **H** of the substrate **41** will be application dependent, and as before, the temperature must not exceed a temperature limit for the photopolymer shim **36** or for the compliant media **45**. As an example, the support substrate **41** can be heated **H** for about 4.0 hours at a temperature of about 100.0 °C when the compliant media **45** is made from the silicone-based elastomer material. The heating **H** cures the silicone-based elastomer material. Alternatively, the support substrate **41** can be heated **H** for about 4.0 hours at a temperature of about 60.0 °C when the compliant media is made from the amorphous fluoropolymer material. In this case, the heating **H** drys out the amorphous fluoropolymer material.

[0091] After the heating step, the support substrate 41 is cooled down. Preferably, the support substrate **41** is allowed to cool down to a temperature of about a room temperature (i.e. from about 18.0 °C to about 28.0 °C) .

[0092] After the support substrate **41** has cooled down, the shim stock **43** is removed from the support substrate **41**. In **FIG. 24**, the shim stock **43** can be removed by cutting **K** the compliant media **45** along an edge of the shim stock **43** that is adjacent to the photopolymer shim **36.** A knife, razor, or the like can be used to cut **K** the compliant media **45.** After the compliant media **45** is cut **K,** the shim stock **43** can be pulled off of the support substrate **41**. The edge of the shim stock **43** (see dashed line for **K)** should be used as a guide for making the cut **K** because the portion **45c** of the compliant media **45** adheres to the surface **41s** of the support substrate **41** and the adhesion prevents the compliant media **45** from being prematurely separated from the substrate **41.**

[0093] In **FIGS. 25** through **27,** a first adhesive surface $\mathbf{A_1}$ of a transfer adhesive layer **51** is applied to a surface **45s** of the compliant media **45** so that the transfer adhesive layer **51** adheres to the compliant media **45.** The transfer adhesive layer **51** includes a seventh thickness $\mathbf{t_7}$ and a second adhesive surface $\mathbf{A_2}$ as will be described below.

[0094] In **FIG. 25,** the first adhesive surface $\mathbf{A_1}$ can be exposed, prior to being applied to the surface **45s,** by peeling back $\mathbf{P_1}$ a first backing **53** from the transfer adhesive layer **51.** Similarly, the second adhesive surface $\mathbf{A_2}$ can be exposed by peeling back $\mathbf{P_2}$ a second backing **55** from the transfer adhesive layer **51.** The first adhesive surface $\mathbf{A_1}$ can be connected with the surface **45s** by using a roller **59** (see **FIG. 26).**

[0095] In **FIG. 26,** the first adhesive surface $\mathbf{A_1}$ is positioned at an edge of the compliant media **45** and then the roller **59** is rolled **R** across the second backing **55** to progressively apply the first adhesive surface $\mathbf{A_1}$ across the surface **45s** until the entire surface **45s** is connected with the first adhesive surface $\mathbf{A_1}$ (see **FIG. 27).** The roller **59** can be a rubber roller, for example. The roller **59** allows the first adhesive surface $\mathbf{A_1}$ to be applied to the surface **45s** without trapping air between the first adhesive surface $\mathbf{A_1}$ and the surface **45s.**

[0096] The seventh thickness $\mathbf{t_7}$ of the transfer adhesive layer **51** will be application dependent. However, because the transfer adhesive layer **51** will remain attached to the compliant media **45** and because it is desirable for the compliant media **45** to be flexible, the transfer adhesive layer **51** should be as thin as possible. Preferably, the seventh thickness $\mathbf{t_7}$ of the transfer adhesive layer **51** is from about 20.0 μm thick to about 100.0 μm thick.

[0097] Preferably, the transfer adhesive layer **51** is an optically transparent material so that another photopolymer material that is brought into contact with the compliant media **45** and the imprint stamp **20t** can be cured by a light source that is incident on both the transfer adhesive layer **51** and the compliant media **45** as will be described below.

[0098] A suitable optically transparent material for the transfer adhesive layer **51** includes but is not limited to an **Adhesives Research, Inc.™ ARclear™ DEV-8932** optically clear silicone adhesive. For instance, a 25.0 μm thick sheet (i.e the seventh thickness $\mathbf{t_7}$ = 25.0 μm) of **ARclear™ DEV-8932** can be used for the transfer adhesive layer **51.**

[0099] In **FIG. 28,** the compliant media **45** can be separated from the support substrate **41** by using a knife, razor, suction wand, tweezer, or the like to initiate the separation of the compliant media **45** from the support substrate **41** as depicted by the knife **K.** In **FIG. 29,** an example of the features (i.e. patterns) that comprise the imprint stamp **20t** are depicted in greater detail. In **FIG. 30,** after the peeling, the compliant media **45** is still connected with the photopolymer shim **36** and the thin plastic film **33.**

[0100] An additional advantage of the method of the present invention is that the photopolymer shim **36** and the thin plastic film **33** layer protect the imprint stamp **20t** from damage during subsequent processing and handling steps that will be described below in reference to **FIGS. 31** through **37b.** Those processing and handling steps can be completed and then the photopolymer shim **36** and the thin plastic film **33** layers can be peeled off to expose the imprint stamp **20t.** Because the photopolymer shim **36** and the thin plastic film **33** layers will eventually be separated from the compliant media **45** in order to expose the imprint stamp **20t** carried by the compliant media **45,** hereinafter, unless otherwise noted, the combination of the layers comprising the photopolymer shim **36** and the thin plastic film **33** will be denoted as the photopolymer shim **36** (see **FIG. 30).**

[0101] Similarly, because the transfer adhesive layer **51** will remain connected with the compliant media **45,** the combination of the compliant media **45** and the transfer adhesive layer **51** will be denoted as a compliant media **70**. In **FIGS. 28** and **30**, the combination of the compliant media **70** and the photopolymer shim **36** will be denoted as a compliant assembly **75.** As will be described below, the compliant assembly **75** will be connected with a cylinder and a flexible belt material.

[0102] In **FIGS. 31a, 31b,** and **31c** an L-shaped jig **73** that includes a horizontal section **73h** and a vertical section **73v** that forms a low vertical wall. The horizontal and vertical sections **(73h, 73v)** are at a right angle β to each other. The sections **(73h, 73v)** should be smooth and substantially flat. The L-shaped jig **73** can be used to effectuate a laminating of the compliant assembly **75** to a surface **69s** of a cylinder **69.**

[0103] In **FIGS. 31a** and **31b**, the support substrate **41** can be placed on the horizontal section **73h** and abutted against the vertical section **73v.** Alternatively, if the compliant assembly **75** has already been separated from the support substrate **41,** then a bed made from a smooth and flat piece of silicone rubber (not shown) can placed on the horizontal section **73h** and an end of the bed is abutted against the vertical section **73v**. The compliant assembly **75** is placed on top of the bed and is aligned with the vertical section **73v** by using the vertical section **73v** as a vertical straight edge. If the second backing **55** is still on the transfer adhesive layer **51,** then the second backing **55** can be peeled off $\mathbf{P_2}$ to expose the second adhesive surface $\mathbf{A_2}$.

[0104] In **FIGS. 31a** and **31c**, a cylinder **69** having an outer surface **69s** is aligned with the horizontal section **73h** and the vertical section **73v** so that the outer surface **69s** is tangent **73t** to those sections **(73h, 73v).** The cylinder **69** is lowered onto the compliant assembly **75** so that the second adhesive surface $\mathbf{A_2}$ is in contact with a portion of the outer surface **69s** at the tangent point **73t.** The cylinder **69** is then rolled **R** in a roll direction $\mathbf{R_D}$ to collect the compliant assembly **75** on the outer surface **69s** as the cylinder **69** is rolled **R.** After the compliant assembly **75** is rolled onto the cylinder **69,** there may be a gap **70g** between adjacent ends of the compliant assembly **75** as depicted in FIG. 31 b.

[0105] Suitable materials for the cylinder **69** include but are not limited to metal, ceramic, glass, quartz, and plastic. Preferably, the cylinder **69** is made from an optically transparent material so that light **L** can pass though the cylinder **69,** the compliant media **70,** and the imprint stamp **20t.** Suitable optically transparent materials for the cylinder **69** include but are not limited to glass, quartz, and plastic. In **FIG. 32,** a light source **99,** such as an ultraviolet light source, can be positioned inside or outside of the cylinder **69** to irradiate and cure a photopolymer material (not shown) that is urged into contact with the imprint stamp **20t**. Because the compliant media **70** can be made to any size, the cylinder **69** can include an inside diameter that is sufficient to accommodate the light source **99**. On the other hand, the light source **99** can be small enough to fit within an inside diameter of the cylinder **69.**

[0106] In **FIG. 31b,** an alternative method for attaching the compliant media **45** to the cylinder **69** is depicted. The compliant media is denoted as **45** instead of **70** because the transfer adhesive layer **51** is not connected with the compliant media **45** in **FIG. 31b.** First, the first adhesive surface $\mathbf{A_1}$ of the transfer adhesive layer **51** is exposed by peeling back the first backing **53** (not shown). Second, the outer surface **69s** of the cylinder **69** is connected with the first adhesive surface $\mathbf{A_1}$ and then the cylinder **69** is rolled to collect the transfer adhesive layer **51** on the outer surface **69s.** Third, a portion of the second backing 55 is peeled back to expose a portion of the second adhesive surface $\mathbf{A_2}$. Next, the exposed portion of the second adhesive surface $\mathbf{A_2}$ is connected with the compliant media **45** at the tangent point **73t** and the cylinder **69** is rolled in the roll direction $\mathbf{R_D}$ to collect the compliant media **45** on the cylinder **69** while simultaneously peeling back **55p** a remainder of the second backing **55** to expose the remainder of the second adhesive surface $\mathbf{A_2}$.

[0107] In **FIGS. 32** and **33,** after the compliant assembly **75** has been rolled onto the cylinder 69, there may be an excess portion **75x** of the compliant assembly **75** that must be trimmed so that a majority of the compliant assembly **75** can be smoothly rolled onto the cylinder **69.** As described above, there may be a gap **70g,** if there is, then it is desirable to trim the excess portion **75x** so that the gap **70g** is as small as is practicable. A knife **K** or the like can be used to trim the excess **75x** so that

the compliant assembly **75** lays on the outer surface **69s** without any bulges. In **FIG. 33,** the knife **K** can cut along a direction K_d to effectuate the trimming of the excess **75x** to form a completely laminated cylinder **90.** In **FIG. 33,** the imprint stamps **20t** are depicted in dashed outline because they are still positioned below the photopolymer shim **36** which have not been separated from the compliant media **70.**

[0108] In **FIG. 33,** a line **n-n** thorough the cylinder **69** and the compliant assembly **75** is depicted in greater detail in a cross-sectional view in **FIGS. 34a** and **34b.** In **FIG. 34a,** the compliant assembly **75** is depicted before the excess **75 x** is trimmed. In **FIG. 34b,** the compliant assembly **75** is depicted after the excess **75x** has been trimmed.

[0109] In **FIG. 34a,** the excess portion **75x** comprises the compliant media **70** and the photopolymer shim **36.** Because the thin plastic film **33** (see **FIG. 28)** that is connected with the photopolymer shim **36** may be opaque to light and the photopolymer shim **36** can be optically transparent, the photopolymer shim **36** can be peeled back as denoted by the dashed arrow **P** so that the compliant media **70** (i.e. the optically transparent adhesive **51** and optically transparent compliant media **45)** can be used to sight along an edge $\mathbf{E_s}$ of the compliant assembly **75** that is already connected with the outer surface **69s** of the cylinder **69.**

[0110] A knife cut **K** along the sight line (see dashed line) for the edge $\mathbf{E_s}$ can be used to trim off the excess **75x** so that the unconnected layers of the excess **75x** will align with their respective connected layers, that is: **36'** to **36**; **45'** to **45**; and **51'** to **51**, as depicted in **FIG. 34a.** After the trimming, there may be the small gap 70g between adjacent ends of the compliant assembly **75.**

[0111] In **FIG. 34b,** but for the gap **70g,** the compliant assembly **75** forms an almost continuous layer on the outer surface **69s** of the cylinder **69.** After the trimming, the photopolymer shim **36** can be peeled back **P** to expose the imprint stamp **20t** on the compliant media **70.**

[0112] In **FIGS. 35** and **36,** the compliant assembly **75** is applied to a belt material **81.** Prior to applying the compliant assembly **75** to the belt material **81**, the second backing **55** is peeled off of the transfer adhesive layer **51** to expose the second adhesive surface $\mathbf{A_2}$. Then the second adhesive surface $\mathbf{A_2}$ is progressively applied to a surface **81s** of the belt material **81.** A roller **89,** such as a rubber roller, can be used to roll **R** the compliant assembly **75** in a roll direction $\mathbf{R_D}$.

[0113] The rolling **R** can begin at a first end **(75a, 81a)** and end at a second end **(75b, 81b**) of the compliant assembly **75** and the belt material **81**. After the compliant assembly **75** and the belt material **81** are connected with each other (see **FIG. 36**), then the first and second ends (**81a, 81b**) can be joined to form a belt **100** as depicted in **FIGS. 37a** and **37b.** As described above, a gap **70g** may separate the first and second ends (**75a, 75b**). Splicing tape or the like may be used to cover the gap **70g.** A piece of splicing tape **81t**, or the like, can also be used to connect the first and second ends (**81a, 81b**) of the belt material **81** to form the belt **100.** After the belt **100** is formed, the layers **71** (i.e. **33** and **36**) can be peeled back **P** to expose the imprint stamp **20t** on the compliant media **70.** A suitable splicing tape includes but is not limited to a high temperature silicone based tape.

[0114] The belt material **81** can be an optically transparent material so that light **L** can pass though the belt material **81,** the compliant media **70,** and the imprint stamp **20t.** A suitable optically transparent material for the belt material **81** includes but is not limited to a **DuPont™ Mylar®.** For example, a light source **99,** such as a ultraviolet light source, can be positioned inside or outside of the belt **100** to irradiate and cure a photopolymer material (not shown) that is urged into contact with the imprint stamp **20t.** The belt material **81** can have a thickness $\mathbf{t_B}$ from about 50.0 μm to about 150.0 μm.

[0115] Although several embodiments of an apparatus and a method of the present invention have been disclosed and illustrated herein, the invention is not limited to the specific forms or arrangements of parts so described and illustrated. The invention is only limited by the claims.

Claims

1. An embossing apparatus **200**, comprising:

    a flexible substrate **101** including a coated side **101c** and a base side **101b**;

    a coating unit **300** for depositing a photopolymer material **301** having a first thickness $\mathbf{t_c}$ on the coated side **101c;**

    an embossing belt **100** comprising an optically transparent belt material **81** and an optically transparent complaint media 70 connected with the belt material 81, the compliant media **70** including an optically transparent imprint stamp **20t** having an imprint pattern **20q** therein;

    a plurality of transport rollers **103** connected with the belt material **81** and operative to support the embossing belt **100;**

    a drive unit **110** for imparting a drive motion $\mathbf{W_D}$ to the embossing belt **100** and the flexible substrate **101;**

    a backing drum **105** wrapped by a portion of the base side **101b** and by a portion of the compliant media **70** so that a tension is imparted in the embossing belt **100** and the tension generates a pressure between the flexible substrate **101** and the embossing belt 100,

the drive motion W_D is operative to transport the base side **101b** over the backing drum **105** and to urge the imprint stamp **20t** and the coated side **101c** into contact with each other so that the imprint pattern **20q** is embossed in the photopolymer material **301** and forms a replicate pattern **20u** in the photopolymer materia **301;** and

an ultraviolet light source **99** for irradiating the replicate pattern **20u** with an ultraviolet light **L** through the belt material **81** and the imprint stamp **20t,** the irradiating occurring contemporaneously with the embossing of the replicate pattern **20u.**

2. The embossing apparatus **200** as set forth in Claim 1, wherein the flexible substrate **101** is opaque to the ultraviolet light **L**.

3. The embossing apparatus **200** as set forth in Claim 1, wherein the ultraviolet light source **99** has a position relative to the embossing belt **100** selected from the group consisting of a position inside of the embossing belt **100** and a position outside of the embossing belt **100**.

4. The embossing apparatus **200** as set forth in Claim 1, wherein the ultraviolet light source **99** comprises a UVA ultraviolet light source.

5. The embossing apparatus **200** as set forth in Claim 1, wherein the ultraviolet light **L** includes a wavelength from about 300.0 nanometers to about 400.0 nanometers.

6. The embossing apparatus **200** as set forth in Claim 1, wherein the coating unit **300** comprises a coater selected from the group consisting of a Gravure Coater, a **MICRO GRAVURE COATER**, and a Slot Die coater.

7. The embossing apparatus **200** as set forth in Claim 1, wherein the first thickness t_c of the photopolymer material **301** is in a range from about 0.05 micrometers to about 2.0 micrometers.

8. The embossing apparatus **200** as set forth in Claim 1, wherein at least one of the transport rollers **103** is connected with the drive unit **110** and the drive unit **110** is operative to rotate the transport roller **103** to impart the drive motion W_D to the embossing belt **100** and the flexible substrate **101.**

9. The embossing apparatus **200** as set forth in Claim 1 and further comprising:

a supply reel **107s** for carrying the flexible substrate **101** and for dispensing the flexible substrate **101** to the coating unit **300**.

10. The embossing apparatus **200** as set forth in Claim 1 and further comprising:

a takeup reel **107r** for collecting the flexible substrate **101** after the flexible substrate **101** has been embossed and cured.

11. The embossing apparatus **200** as set forth in Claim 10, wherein the takeup reel is **107r** connected with the drive unit **110** and the drive unit **110** is operative to rotate D_R the takeup reel **107r** to collect the flexible substrate **101** and to impart the drive motion W_D.

12. The embossing apparatus **200** as set forth in Claim 1, wherein the compliant media comprises **70** an optically transparent silicone-based elastomer material **44** that is laminated to an optically transparent transfer adhesive layer **51.**

13. The embossing apparatus **200** as set forth in Claim 12, wherein the optically transparent silicone-based elastomer material **44** is a material selected from the group consisting of Polydimethyl Siloxane, **SYLGARD 182, SYLGARD 183, SYLGARD 184,** and **SYLGARD 186.**

14. The embossing apparatus **200** as set forth in Claim 12, wherein the optically transparent transfer adhesive layer **51** is an **ARclear DEV-8932** optically clear silicone adhesive.

15. The embossing apparatus **200** as set forth in Claim 1, wherein the optically transparent belt material **81** is a material selected from the group consisting of a Polyester film and Mylar.

16. The embossing apparatus **200** as set forth in Claim 1, wherein the ultraviolet light source **99** further includes a reflector **99r** for focusing the ultraviolet light **L** at a point where the imprint stamp **20t** is urged into contact with the coated side **101c** so that the photopolymer material **301** is not cured before the imprint pattern **20q** is embossed in the photopolymer material **301.**

17. An embossing apparatus **200,** comprising:

a flexible substrate **101** including a coated side **101c** and a base side **101b;**

a coating unit **300** for depositing a photopolymer material **301** having a first thickness t_c on the coated side **101c;**

an embossing drum **90** comprising an optically transparent cylinder **69** and an optically transparent complaint media **70** connected with the cylinder **69**, the compliant media **70** including an optically transparent imprint stamp **20t** having an imprint pattern **20q** therein;

a drive unit **110** for imparting a drive motion $\mathbf{W_D}$ to the embossing drum **90** and the flexible substrate **101;**

a plurality of transport rollers **103** connected with the base side **101b** and operative to conformally wrap the coated side **101c** over a portion of the embossing drum **90** so that the embossing drum **90** imparts a tension in the flexible substrate **101** and the tension generates a pressure between the flexible substrate **101** and the embossing drum **90**,

the drive motion $\mathbf{W_D}$ is operative to transport the coated side **101c** over the embossing drum **90** and to urge the imprint stamp **20t** and the coated side **101c** into contact with each other so that the imprint pattern **20q** is embossed in the photopolymer material **301** and forms a replicate pattern **20u** in the photopolymer material **301;** and

an ultraviolet light source **99** for irradiating the replicate pattern **20u** with an ultraviolet light **L** through the cylinder **69** and the imprint stamp **20t**, the irradiating occurring contemporaneously with the embossing of the replicate pattern **20u.**

18. The embossing apparatus **200** as set forth in Claim 17, wherein the flexible substrate **101** is opaque to the ultraviolet light **L**.

19. The embossing apparatus **200** as set forth in Claim 17, wherein the ultraviolet light source **99** has a position relative to the embossing drum **90** selected from the group consisting of a position inside of the embossing drum **90** and a position outside of the embossing drum **90**.

20. The embossing apparatus **200** as set forth in Claim 17, wherein the ultraviolet light source **99** comprises a UVA ultraviolet light source.

21. The embossing apparatus **200** as set forth in Claim 17, wherein the ultraviolet light **L** includes a wavelength from about 300.0 nanometers to about 400.0 nanometers.

22. The embossing apparatus **200** as set forth in Claim 17, wherein the coating unit **300** comprises a coater selected from the group consisting of a Gravure coater, a **MICRO GRAVURE COATER**, and a Slot-die coater.

23. The embossing apparatus **200** as set forth in Claim **17,** wherein the first thickness $\mathbf{t_c}$ is in a range from about 0.05 micrometers to about 2.0 micrometers.

24. The embossing apparatus **200** as set forth in Claim **17,** wherein at least one of the transport rollers **103** is connected with the drive unit **110** and the drive unit **110** is operative to rotate the transport roller **103** to impart the drive motion $\mathbf{W_D}$ to the embossing drum **90** and the flexible substrate **101.**

25. The embossing apparatus **200** as set forth in Claim 17 and further comprising:

a supply reel **107s** for carrying the flexible substrate **101** and for dispensing the flexible substrate **101** to the coating unit **300**.

26. The embossing apparatus **200** as set forth in Claim 17 and further comprising:

a takeup reel **107r** for collecting the flexible substrate **101** after the flexible substrate **101** has been embossed and cured.

27. The embossing apparatus **200** as set forth in Claim 26, wherein the takeup reel **107r** is connected with the drive unit **110** and the drive unit **110** is operative to rotate $\mathbf{D_R}$ the takeup reel **107r** to collect the flexible substrate **101** and to impart the drive motion $\mathbf{W_D}$ to the embossing drum **90** and the flexible substrate **101**.

28. The embossing apparatus **200** as set forth in Claim 17, wherein the compliant media **70** comprises an optically transparent silicone-based elastomer material **44** that is laminated to an optically transparent transfer adhesive layer **51.**

29. The embossing apparatus **200** as set forth in Claim 28, wherein the optically transparent silicone-based elastomer material **44** is a material selected from the group consisting of Polydimethyl Siloxane, **SYLGARD 182, SYLGARD 183, SYLGARD 184,** and **SYLGARD 186.**

30. The embossing apparatus **200** as set forth in Claim 28, wherein the optically transparent transfer adhesive layer **51** is an **ARclear DEV-8932** optically clear silicone adhesive.

31. The embossing apparatus **200** as set forth in Claim 17, wherein the optically transparent cylinder **69** is made from a material selected from the group con-

sisting of a glass, a plastic, and quartz.

32. The embossing apparatus **200** as set forth in Claim 17, wherein the ultraviolet light source **99** further includes a reflector **99r** for focusing the ultraviolet light **L** at a point where the imprint stamp **20t** is urged into contact with the coated surface **101c** so that the photopolymer material **301** is not cured before the imprint pattern **20q** is embossed in the photopolymer material **301.**

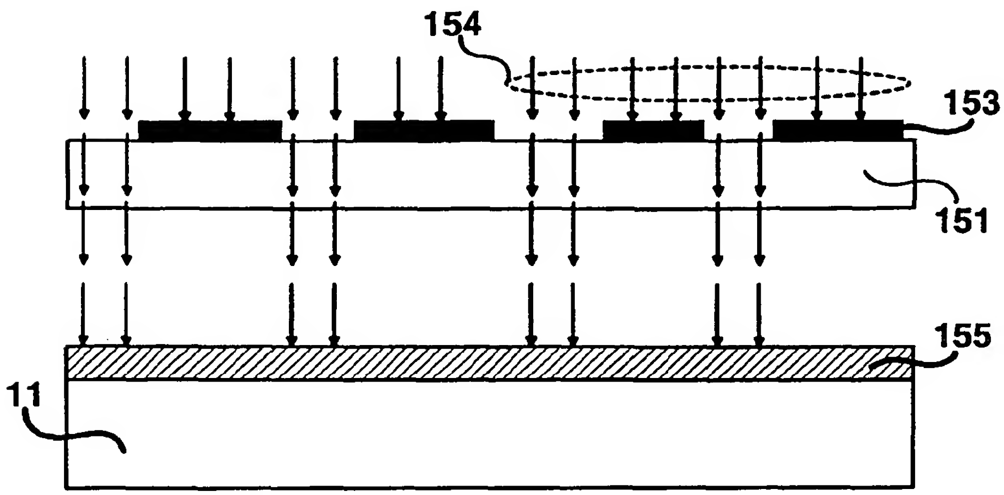

FIG. 1

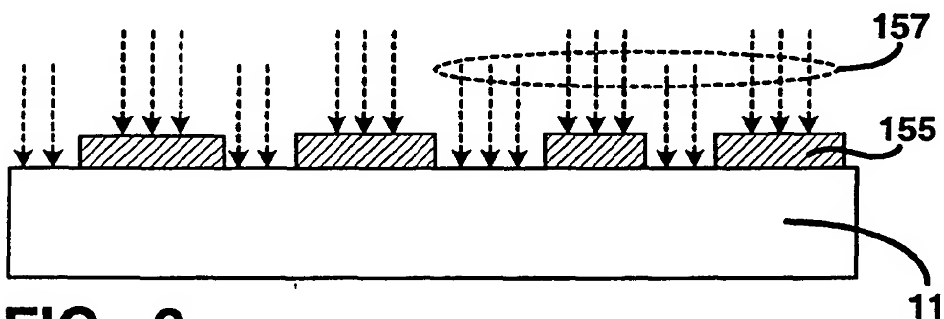

FIG. 2

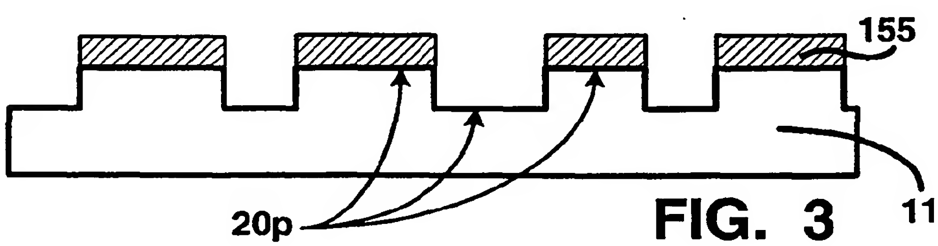

FIG. 3

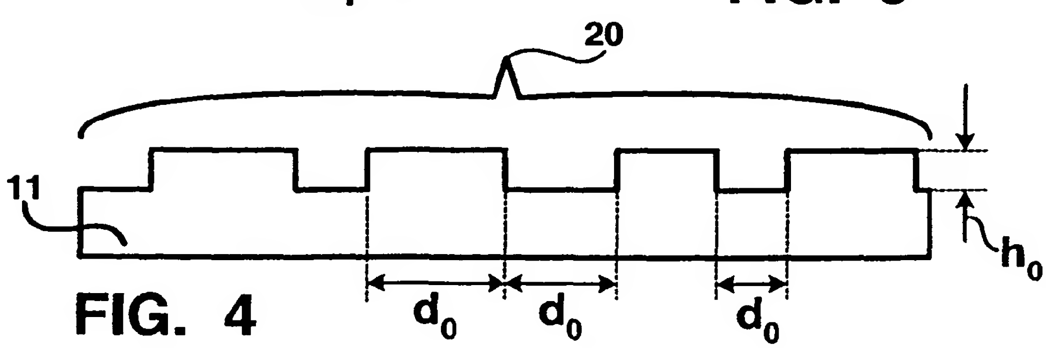

FIG. 4

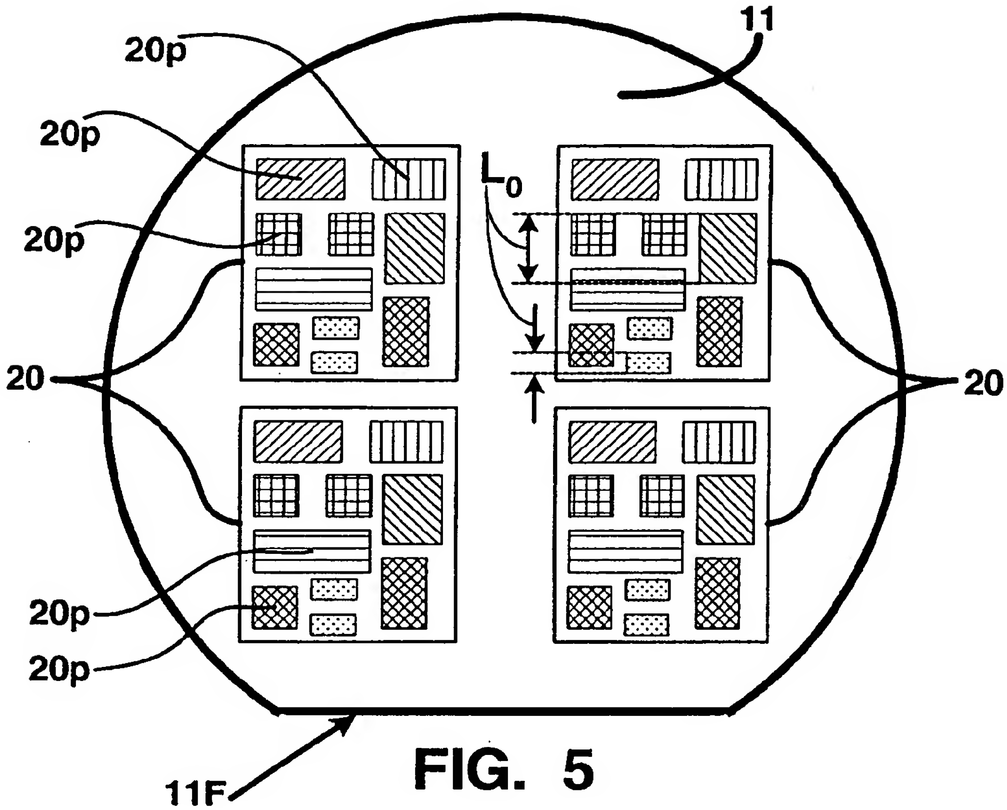

FIG. 5

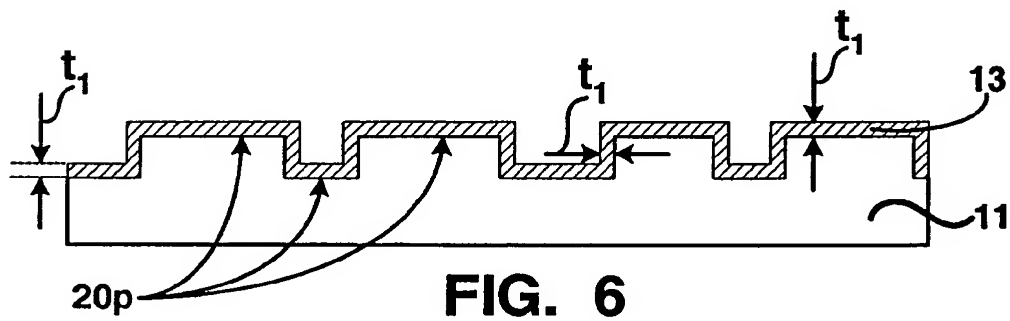

FIG. 6

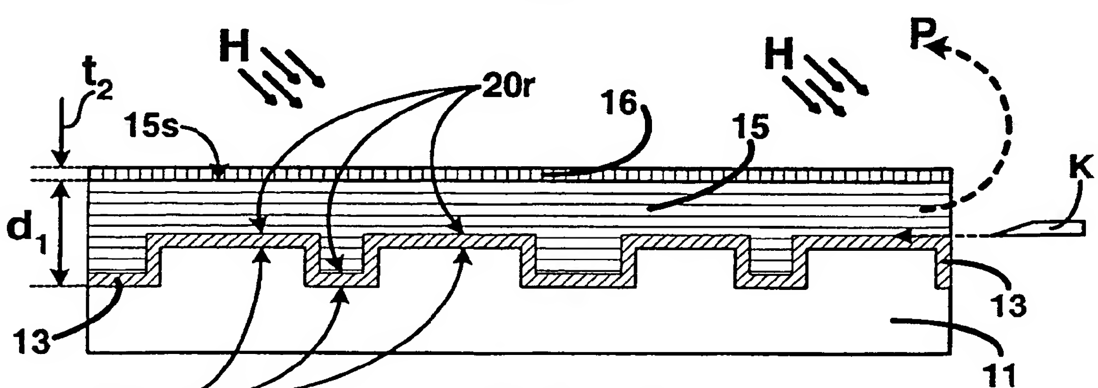

FIG. 7

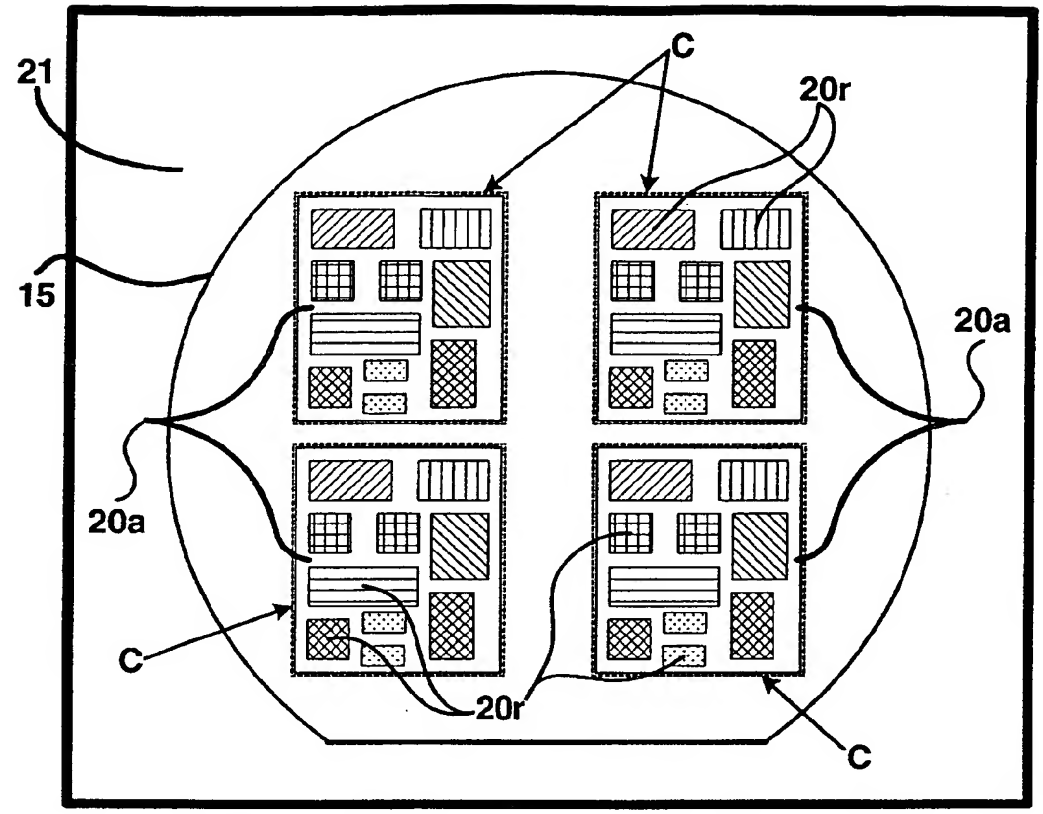

FIG. 8

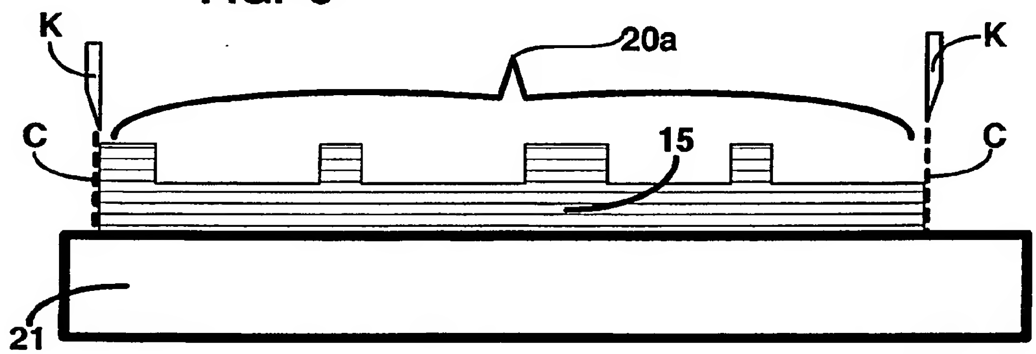

FIG. 9

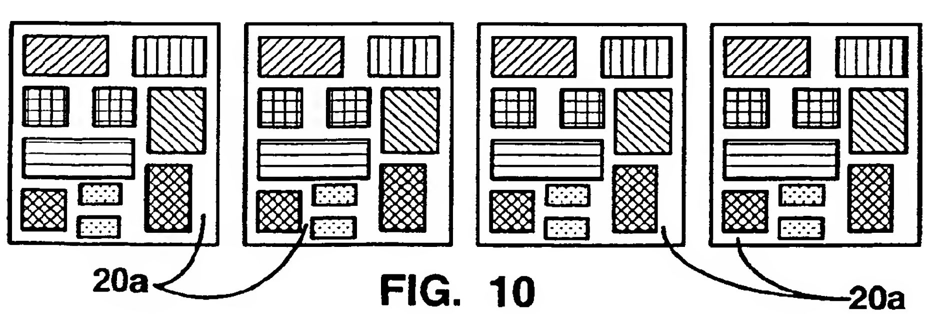

FIG. 10

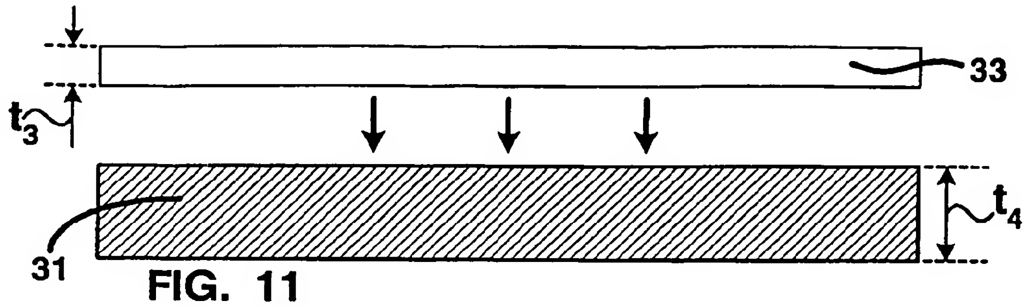

FIG. 11

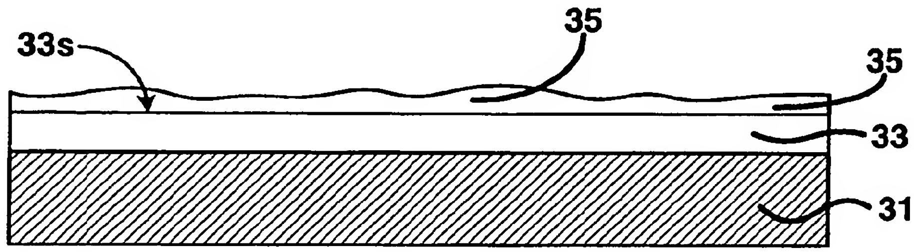

FIG. 12

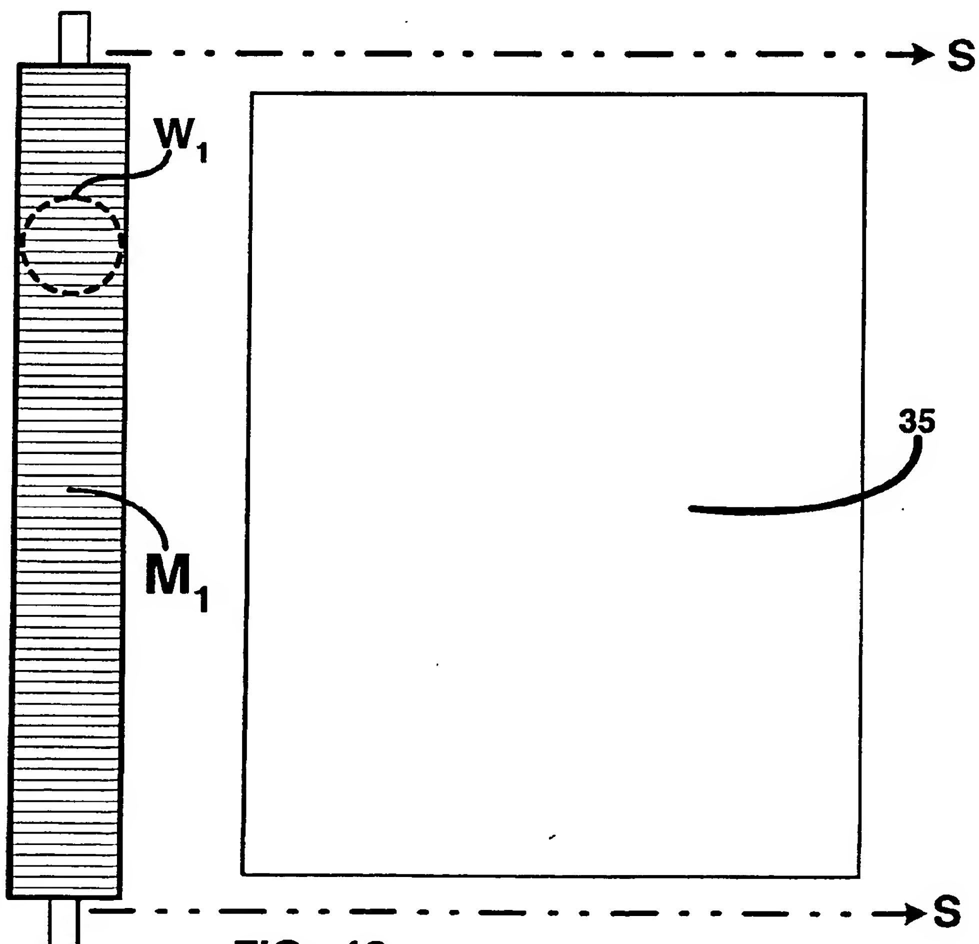

FIG. 13

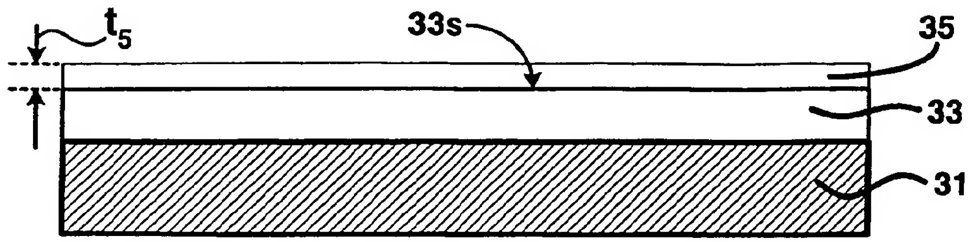

FIG. 14

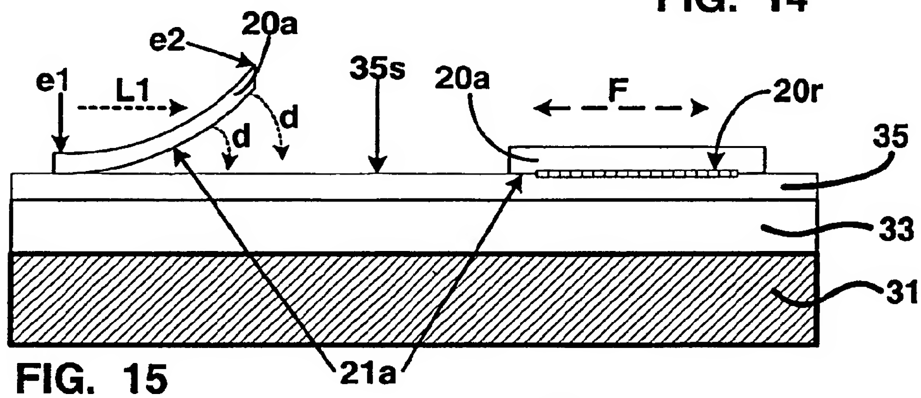

FIG. 15

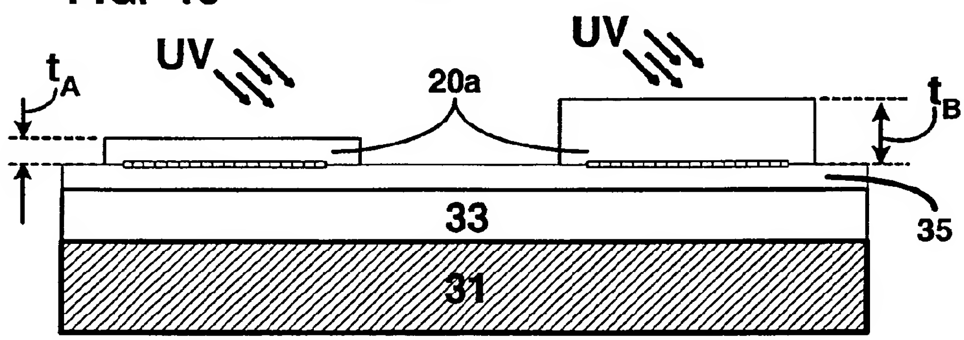

FIG. 16

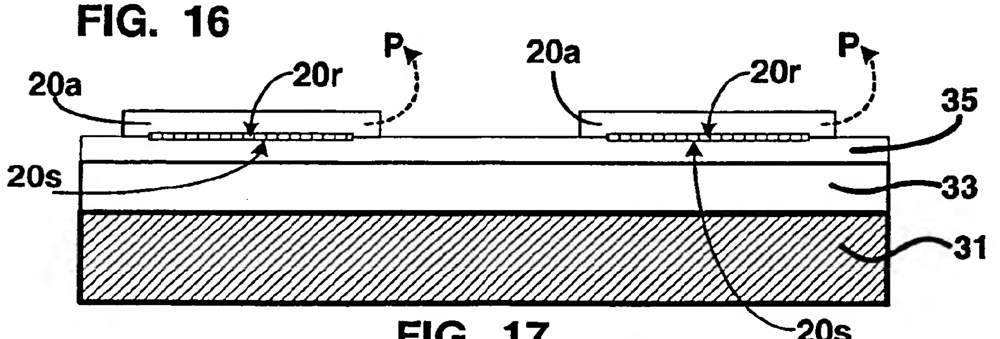

FIG. 17

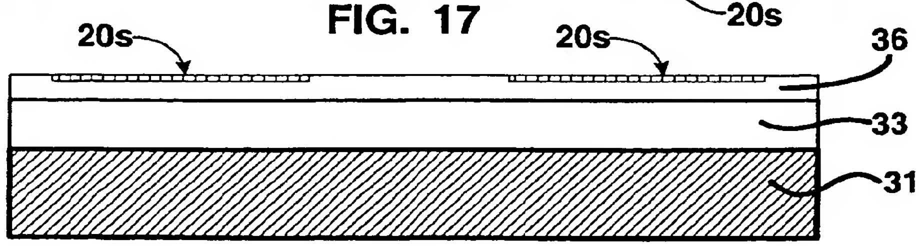

FIG. 18

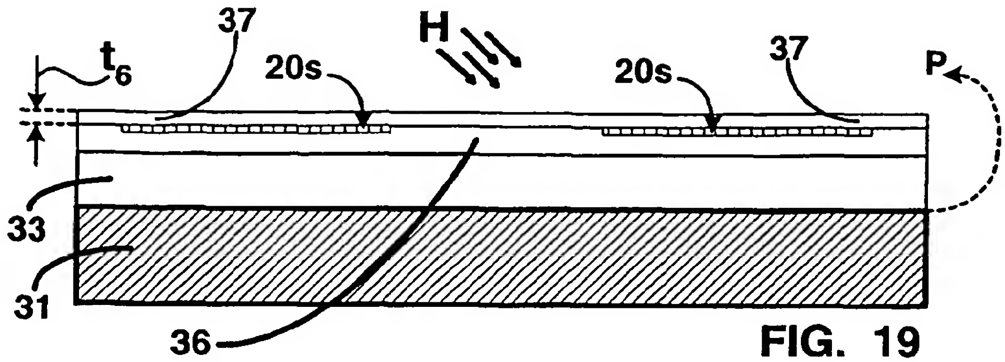

FIG. 19

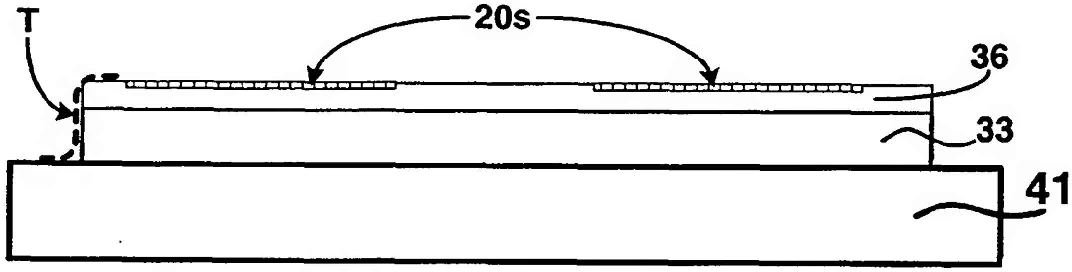

FIG. 20

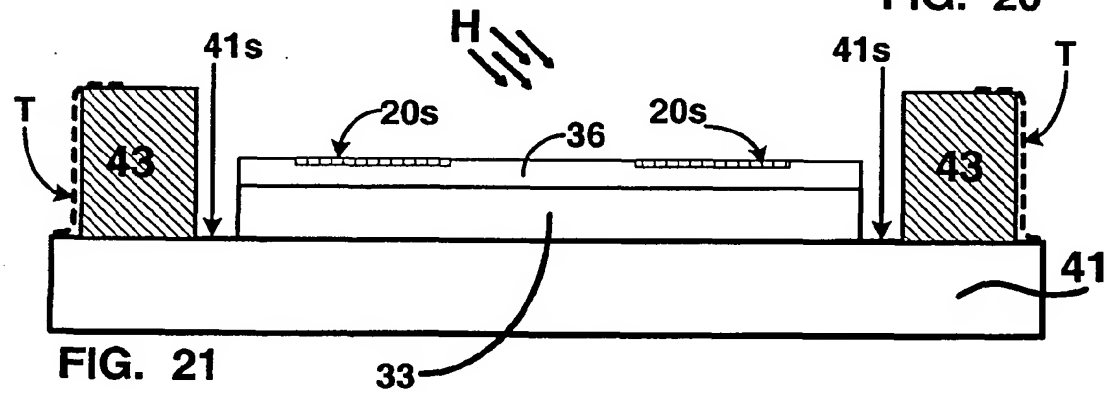

FIG. 21

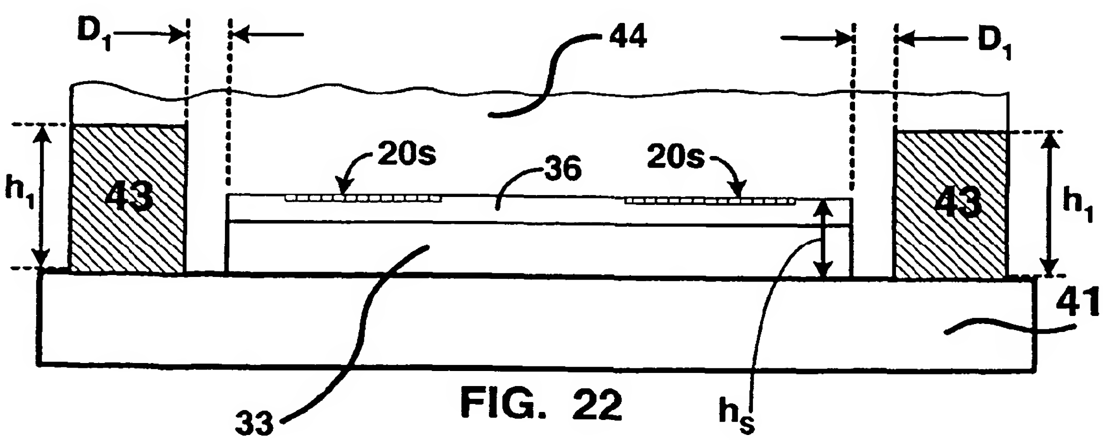

FIG. 22

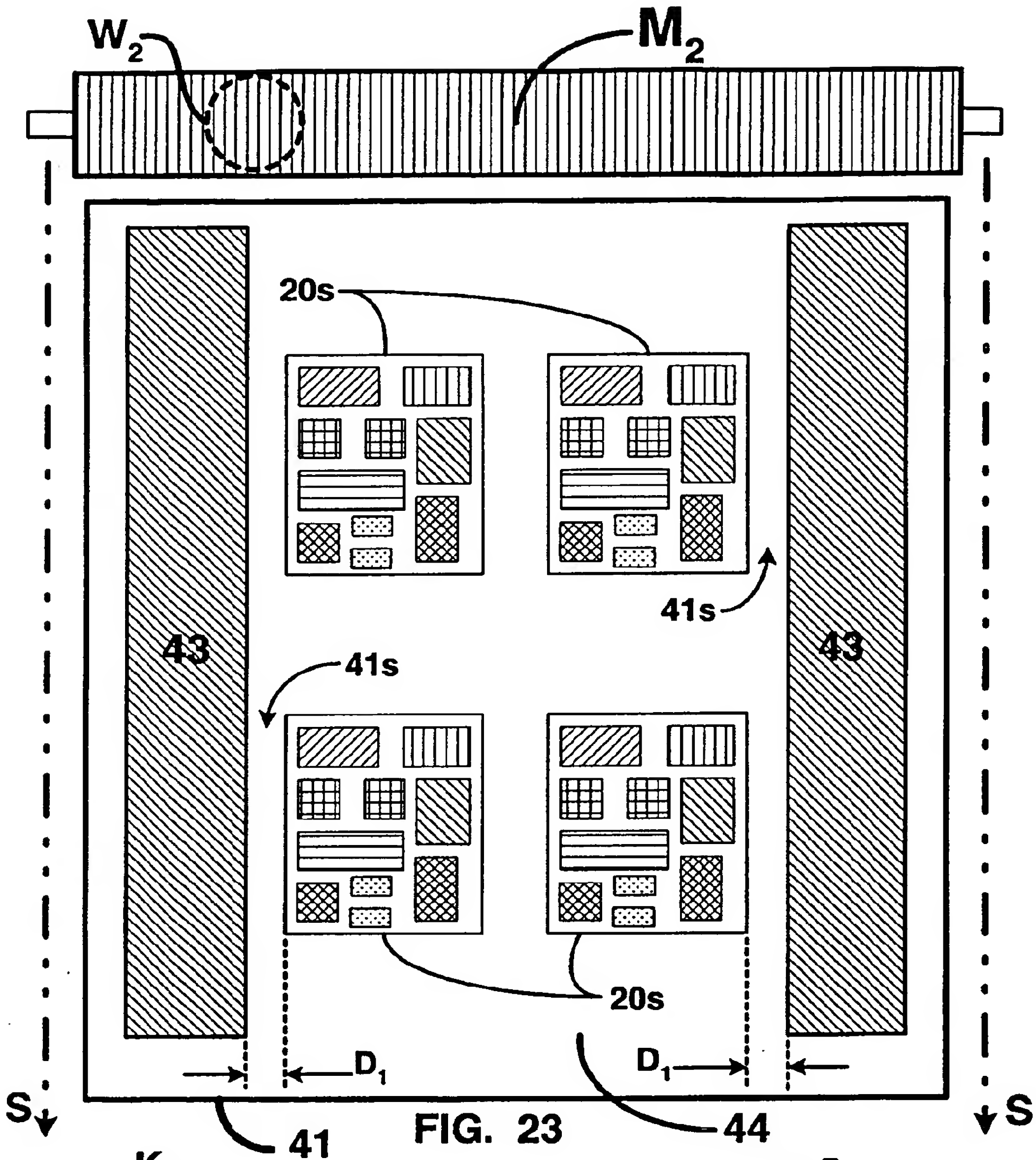
W2
M2
20s
41s
43
43
41s
20s
D1
D1
S
S
41
44

FIG. 23

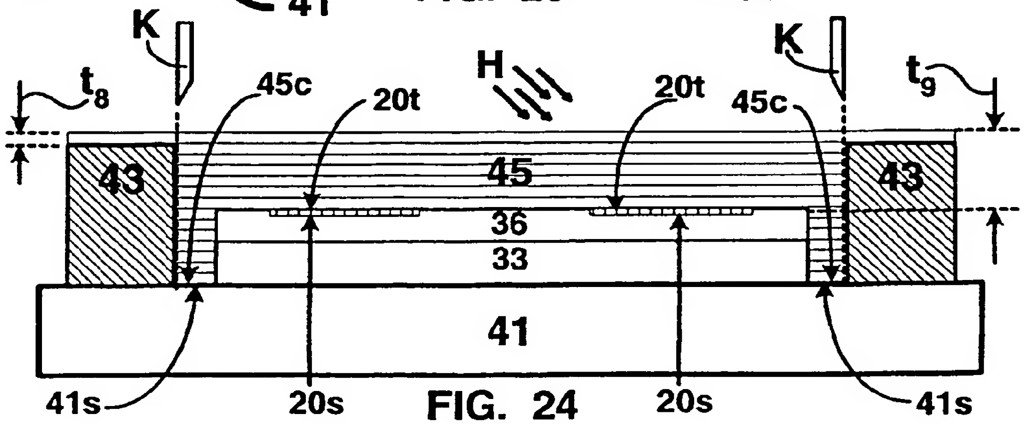
K
K
H
t8
45c
20t
20t
45c
t9
43
45
43
36
33
41
41s
20s
20s
41s

FIG. 24

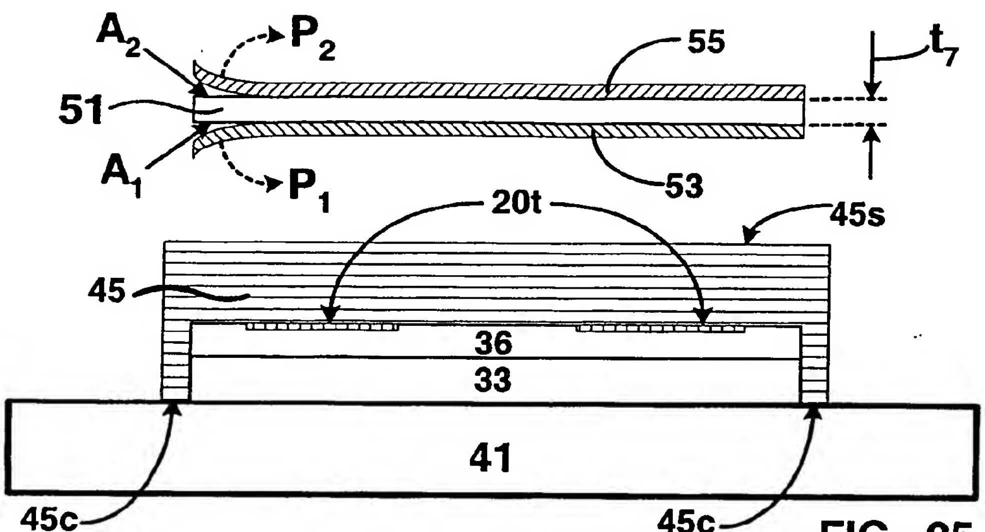

FIG. 25

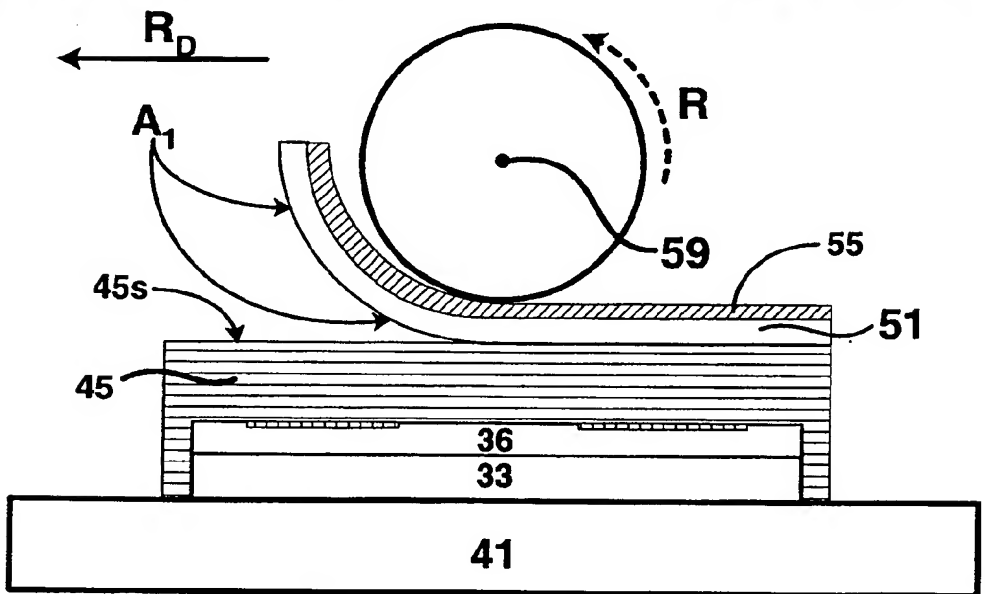

FIG. 26

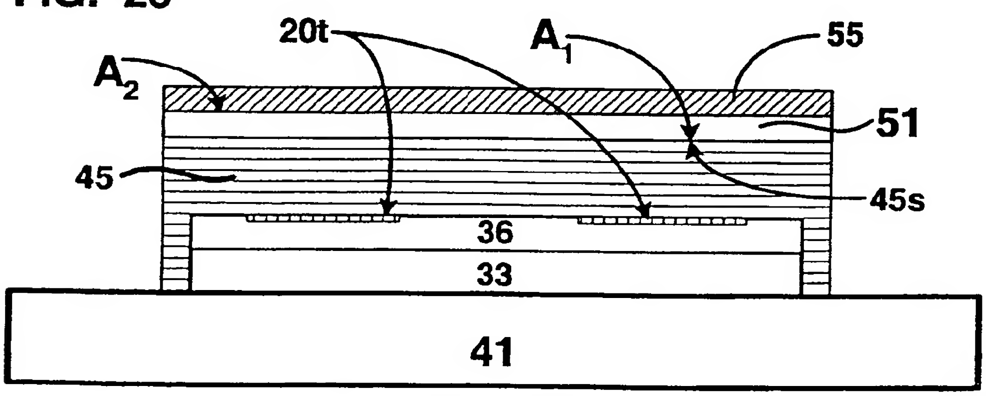

FIG. 27

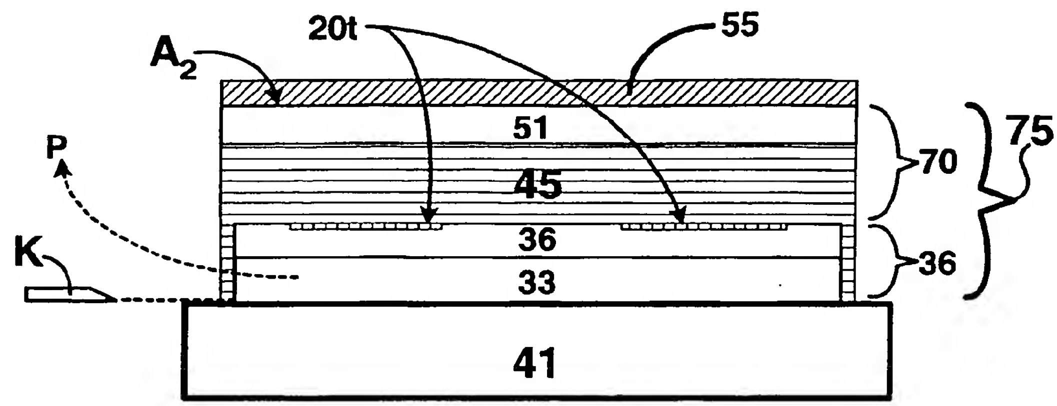

FIG. 28

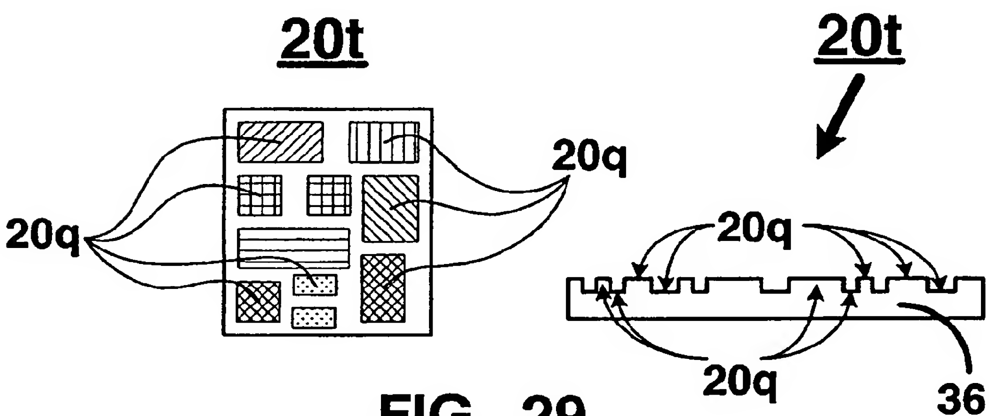

FIG. 29

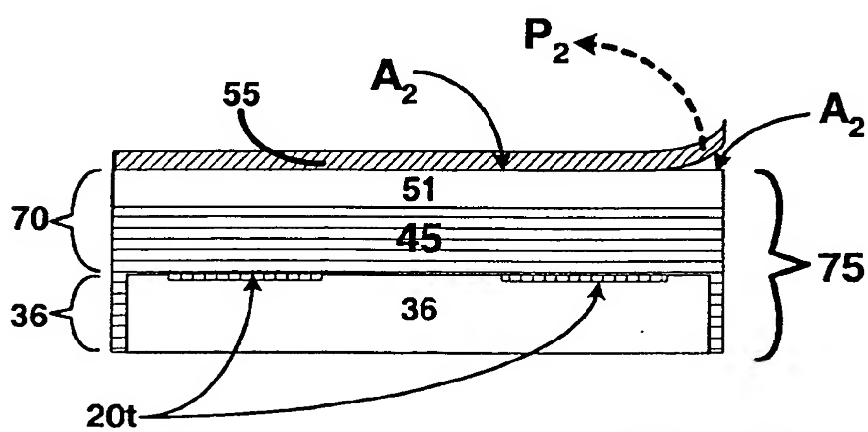

FIG. 30

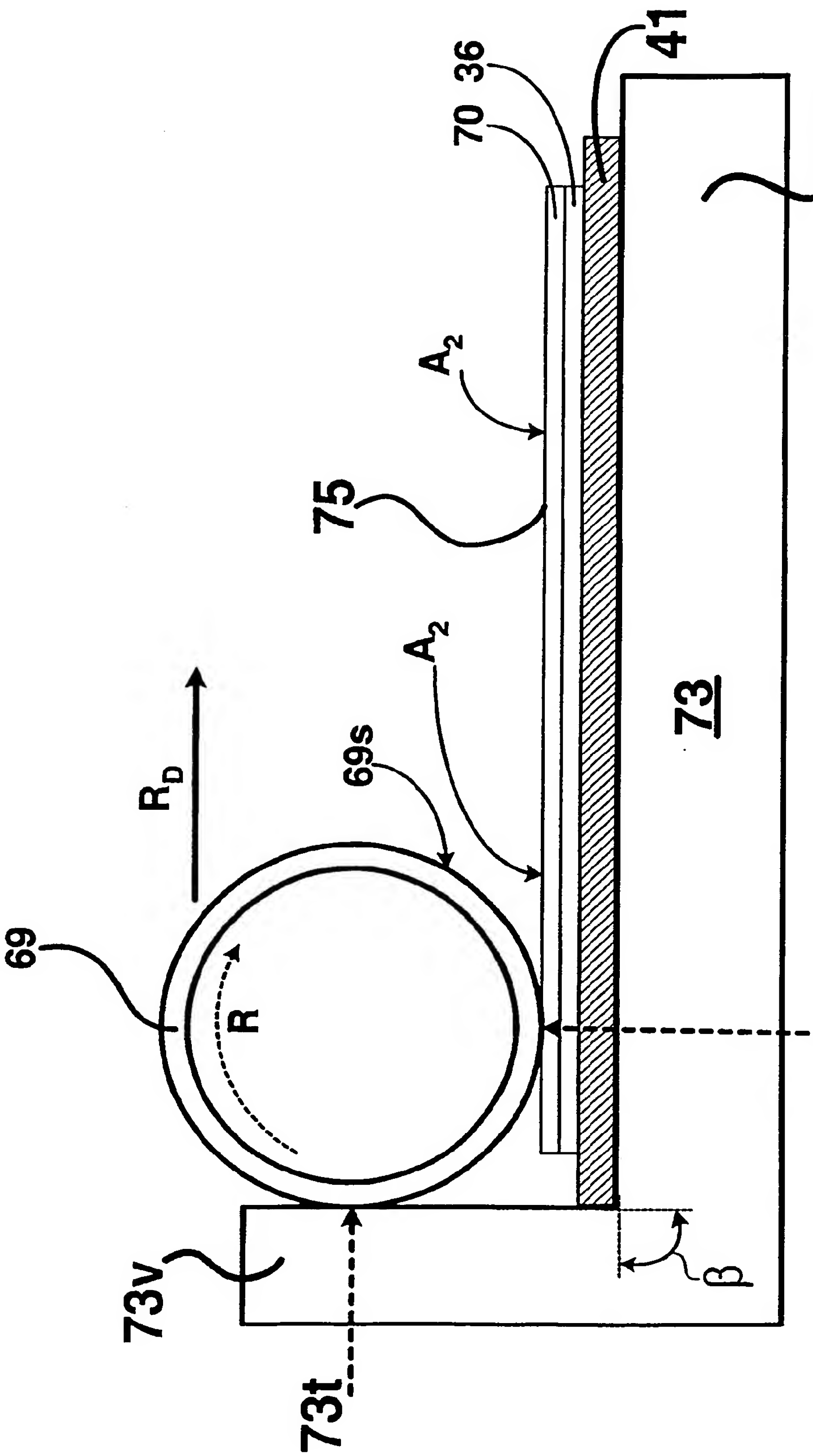

FIG. 31a

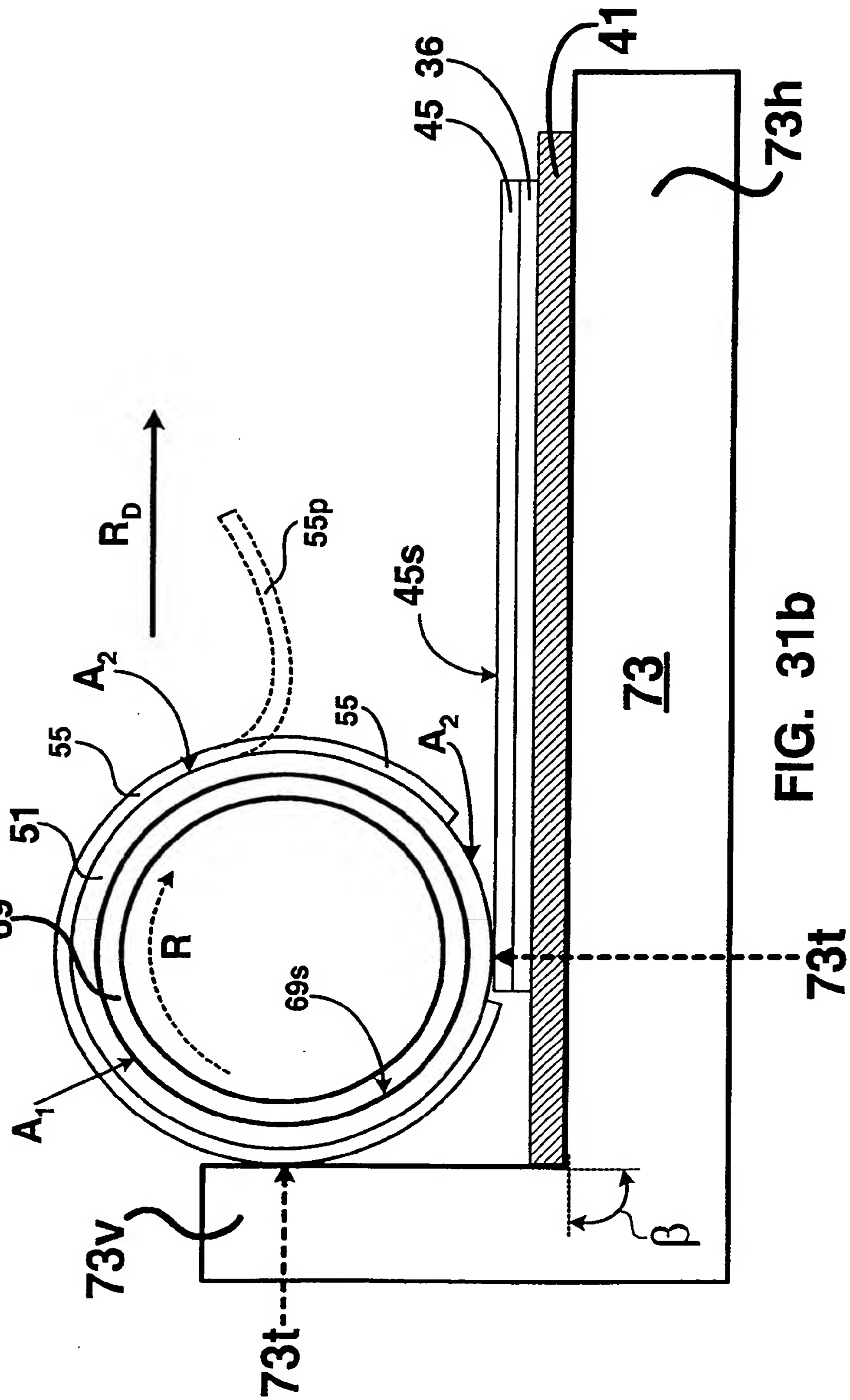

FIG. 31b

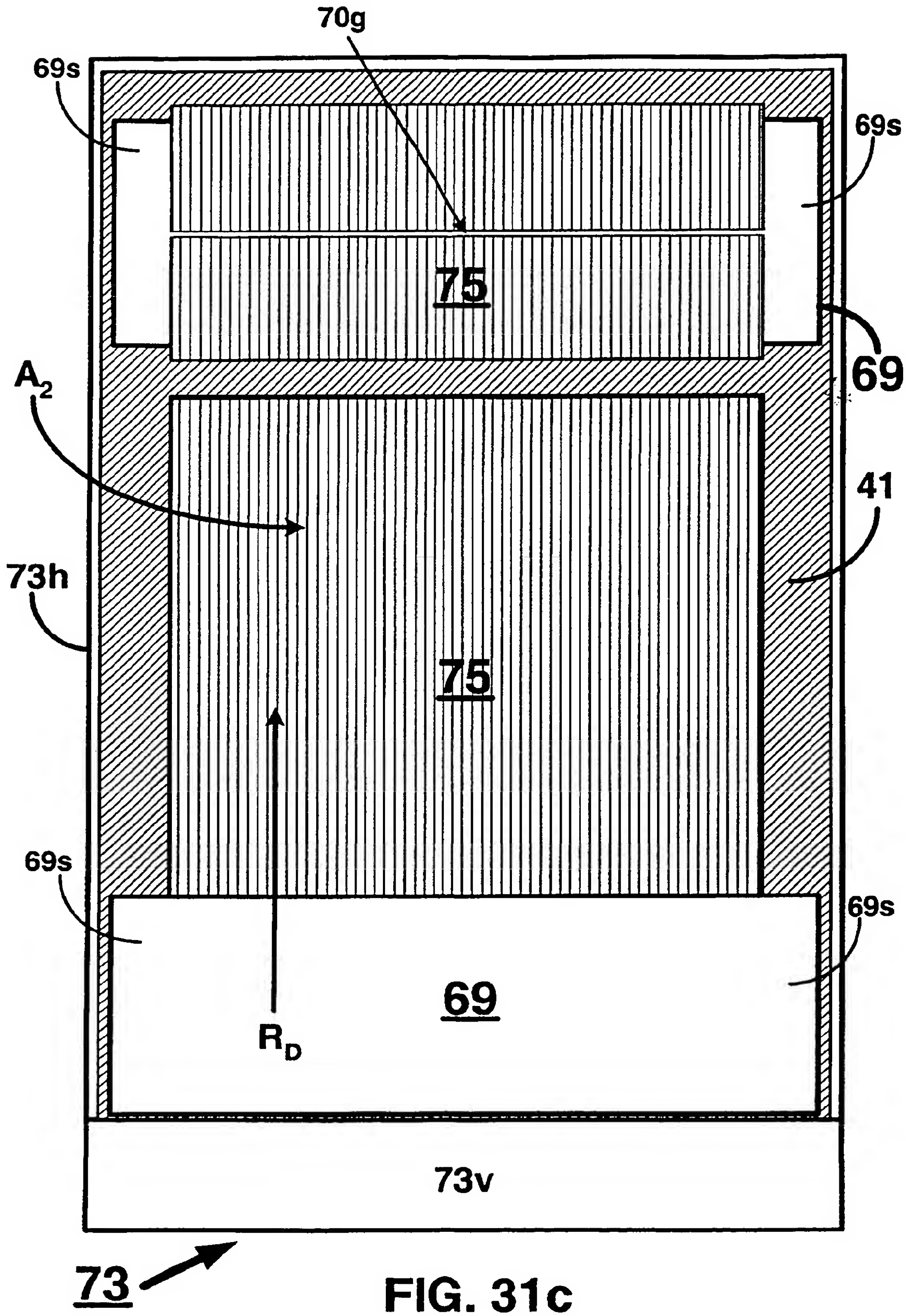

FIG. 31c

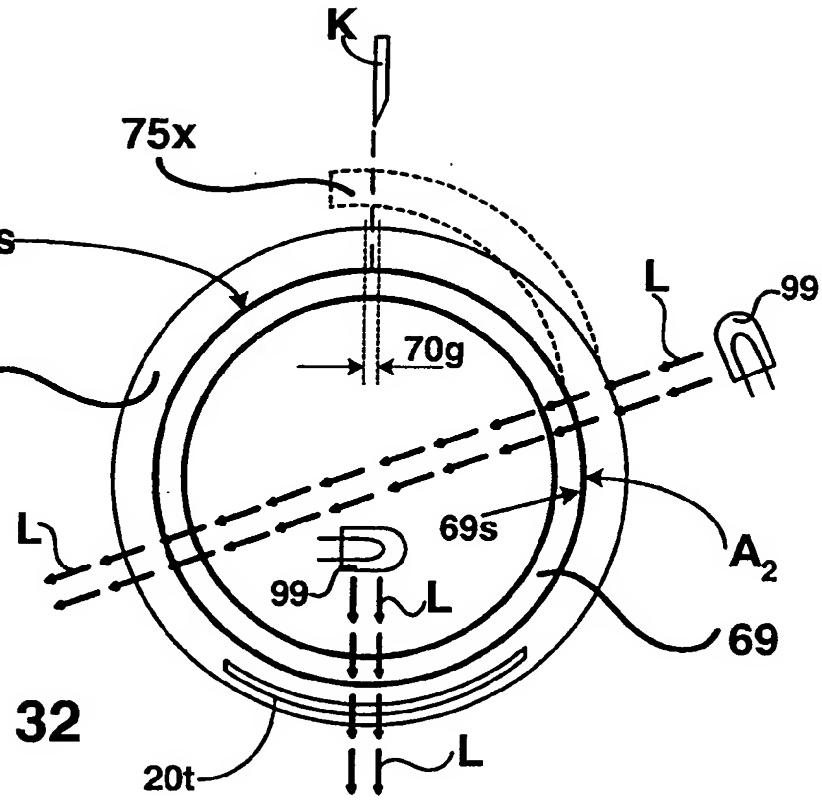
K
75x
69s
L
99
70g
75
69s
A2
L
99
L
69
20t
L

FIG. 32

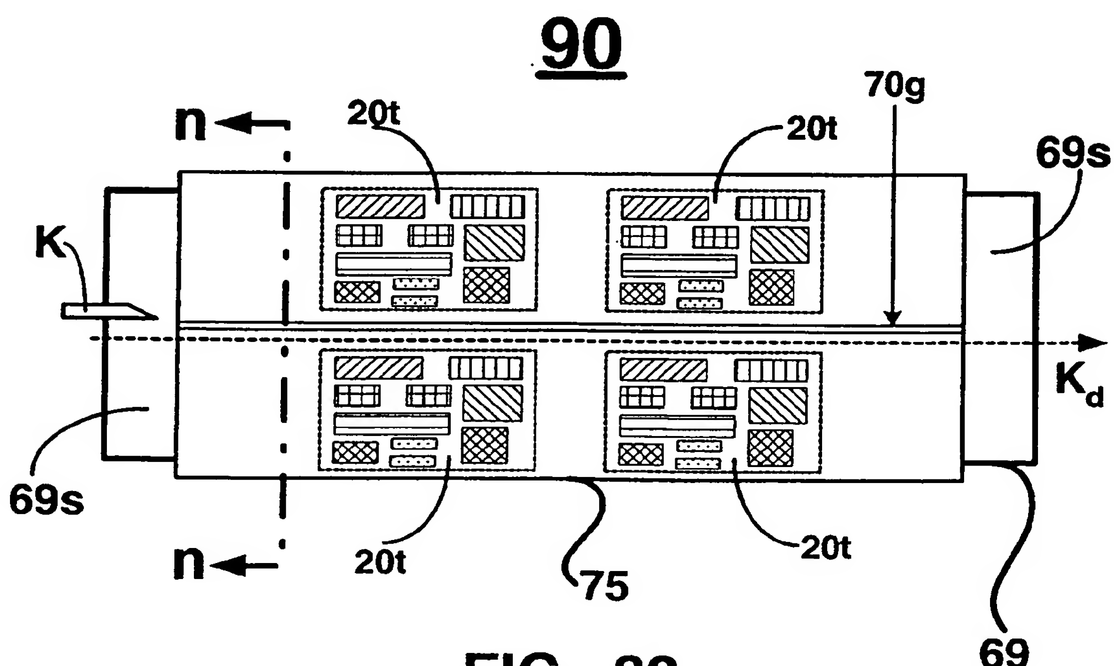
90
70g
n
20t
20t
69s
K
Kd
69s
n
20t
75
20t
69

FIG. 33

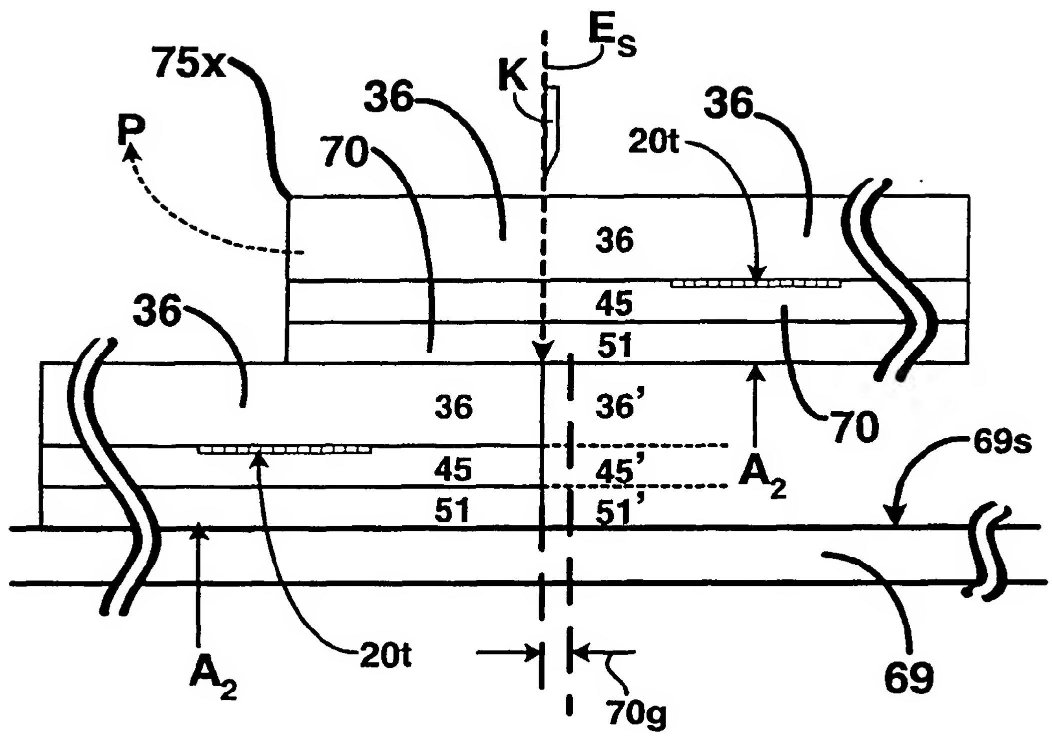

FIG. 34a

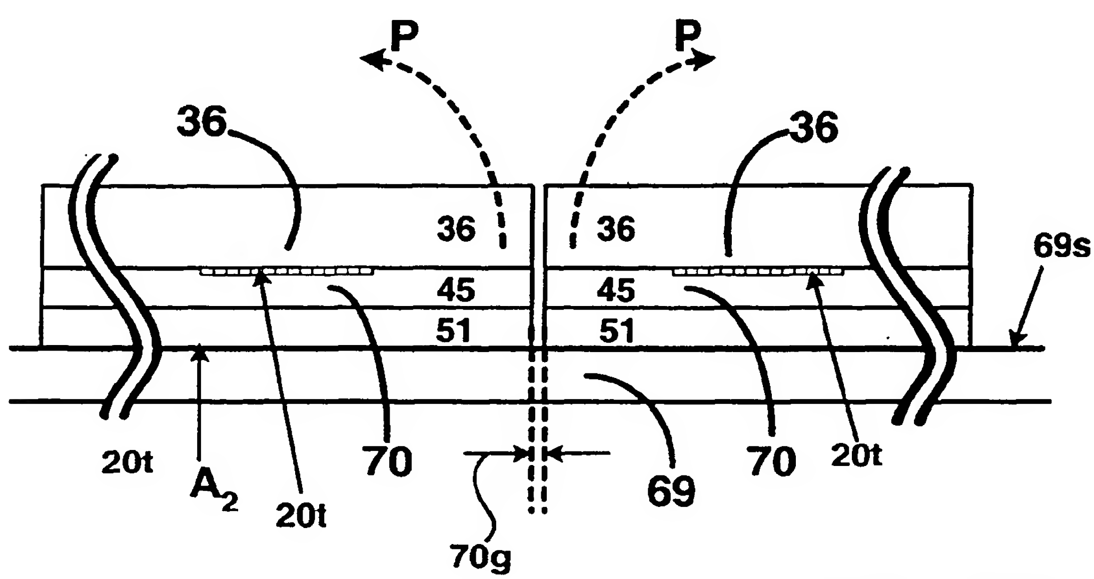

FIG. 34b

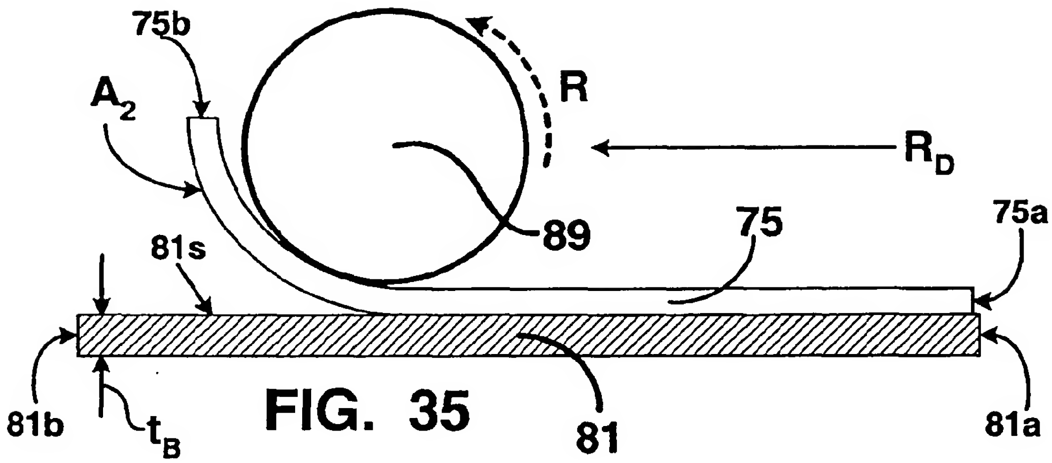

FIG. 35

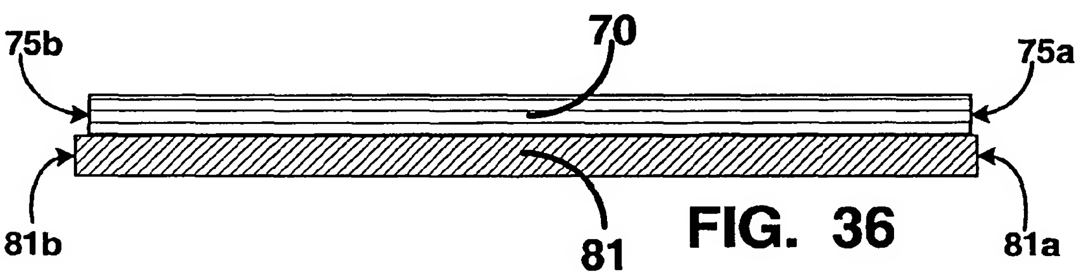

FIG. 36

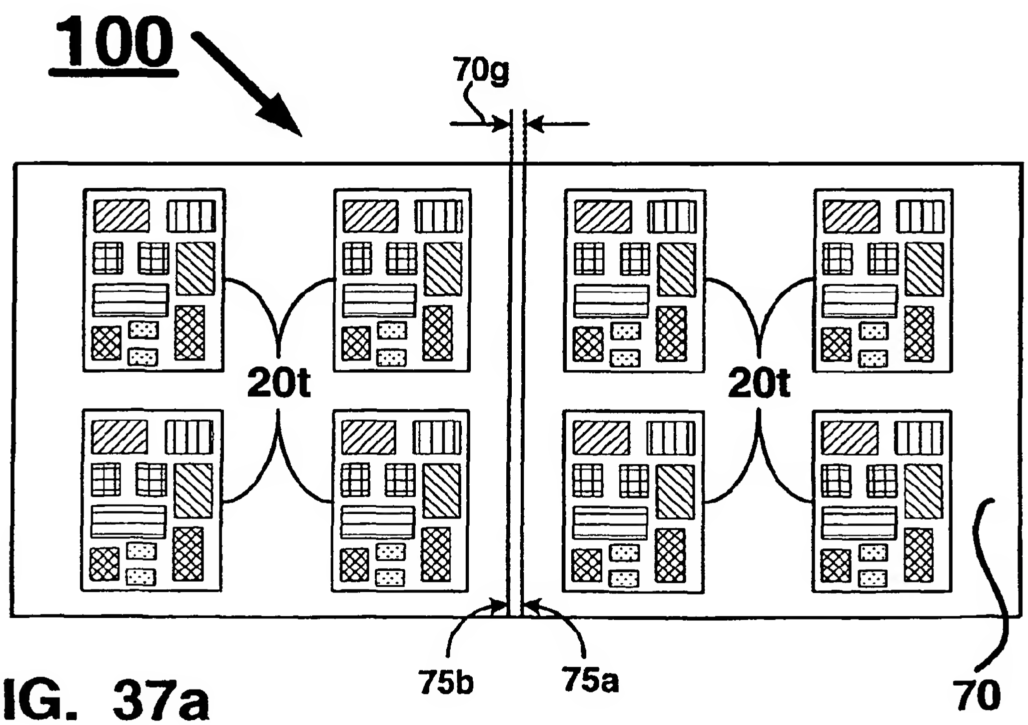

FIG. 37a

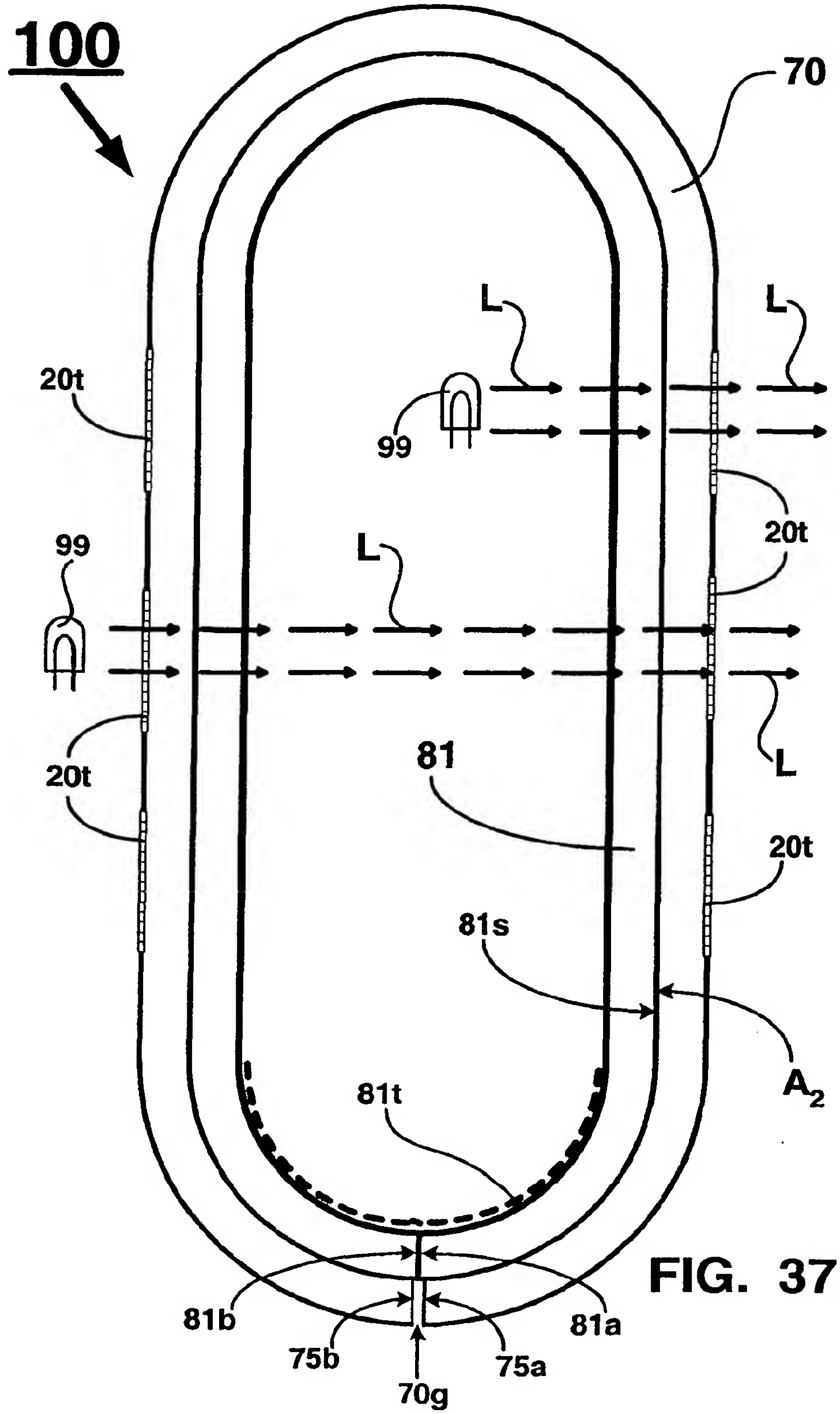
100
70
L
L
20t
99
99
L
20t
20t
L
81
20t
81s
A2
81t
81b
81a
75b
75a
70g

FIG. 37b

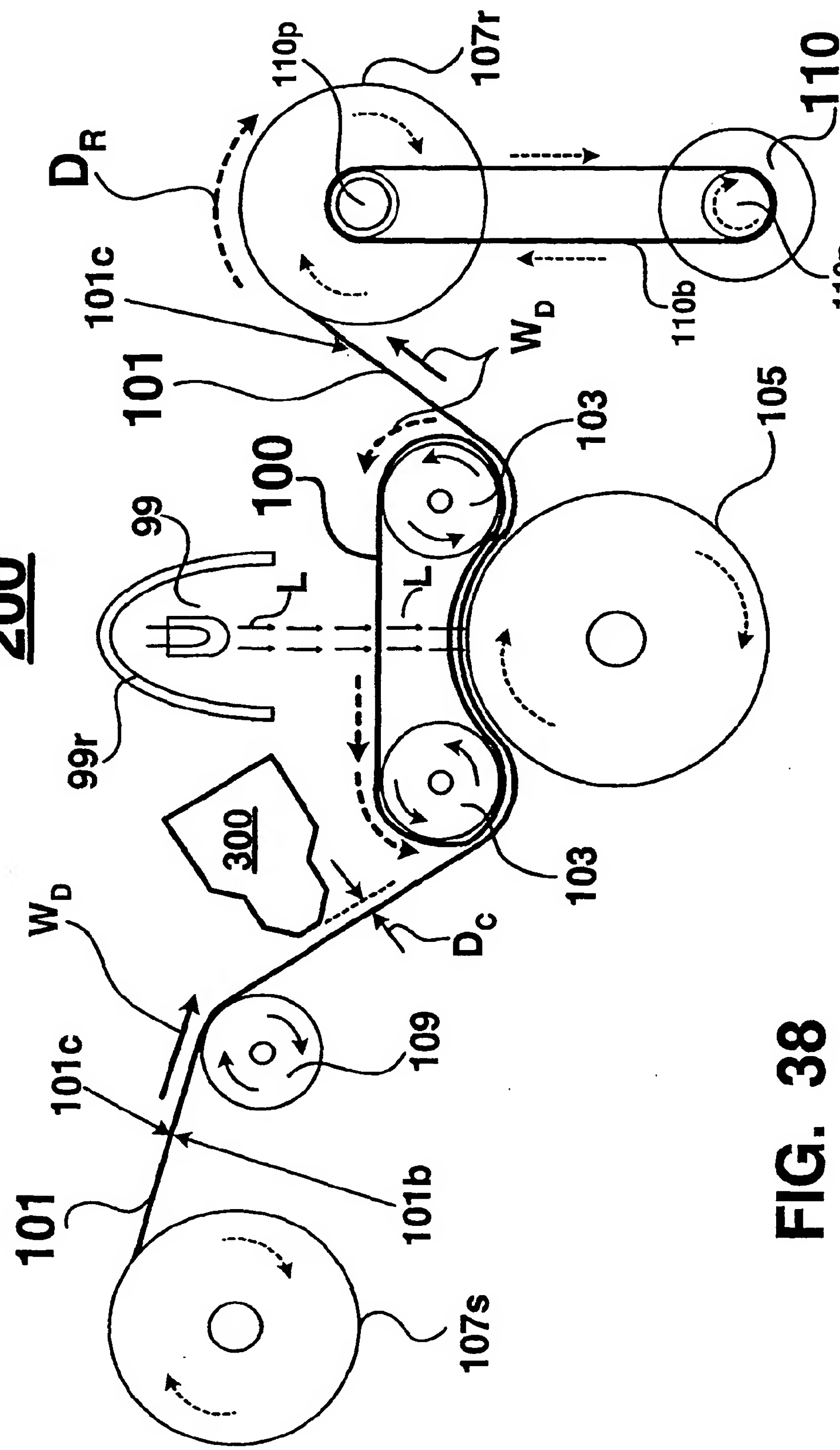
200
99
99r
L
L
100
300
101
101
101c
101c
101b
W_D
W_D
D_R
D_C
103
103
105
107r
107s
109
110
110p
110p
110b

FIG. 38

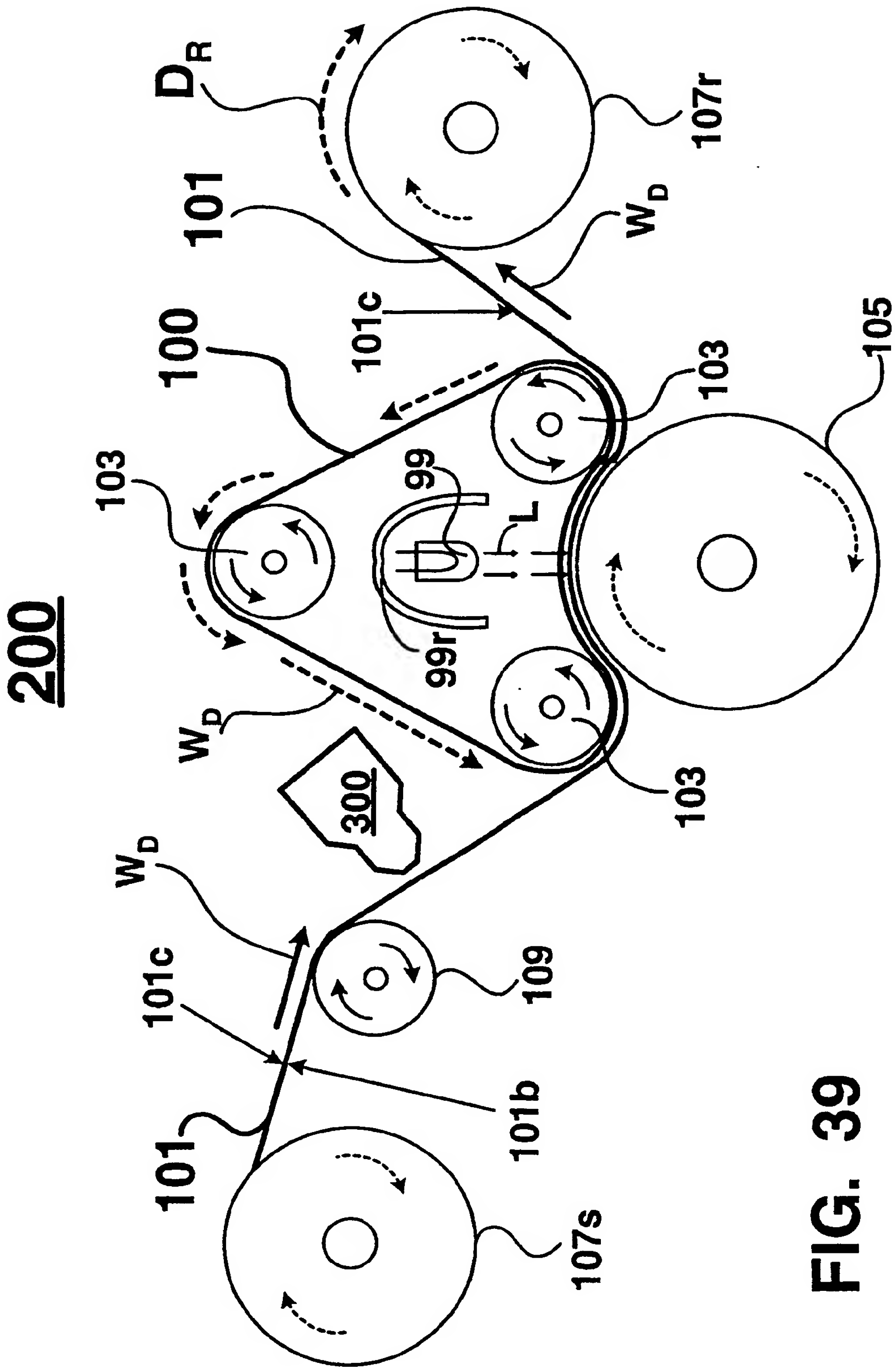

FIG. 39

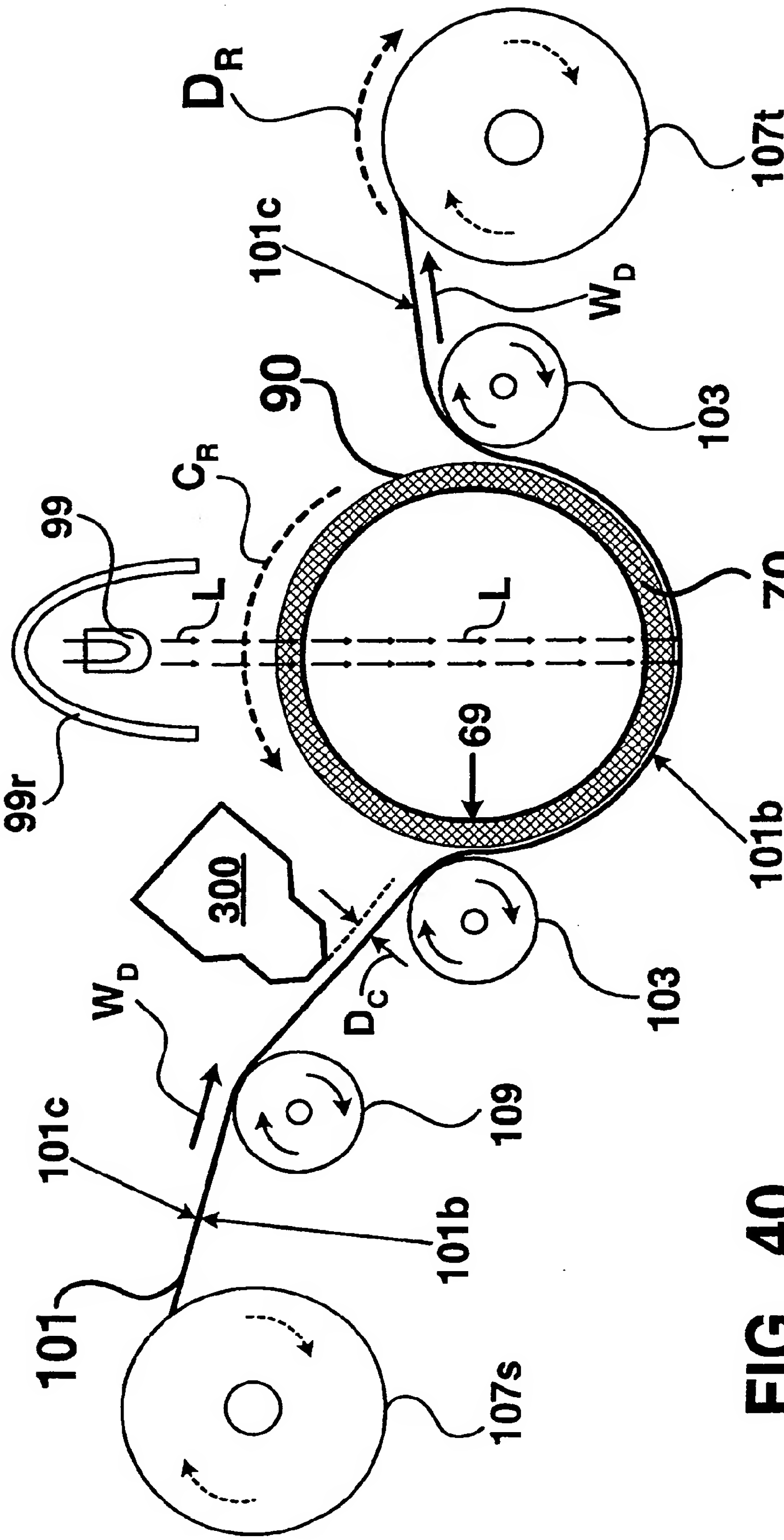
200
99r
99
L
L
C_R
69
90
70
101b
300
D_C
103
103
W_D
101c
101b
109
101
107s
D_R
101c
W_D
107t

FIG. 40

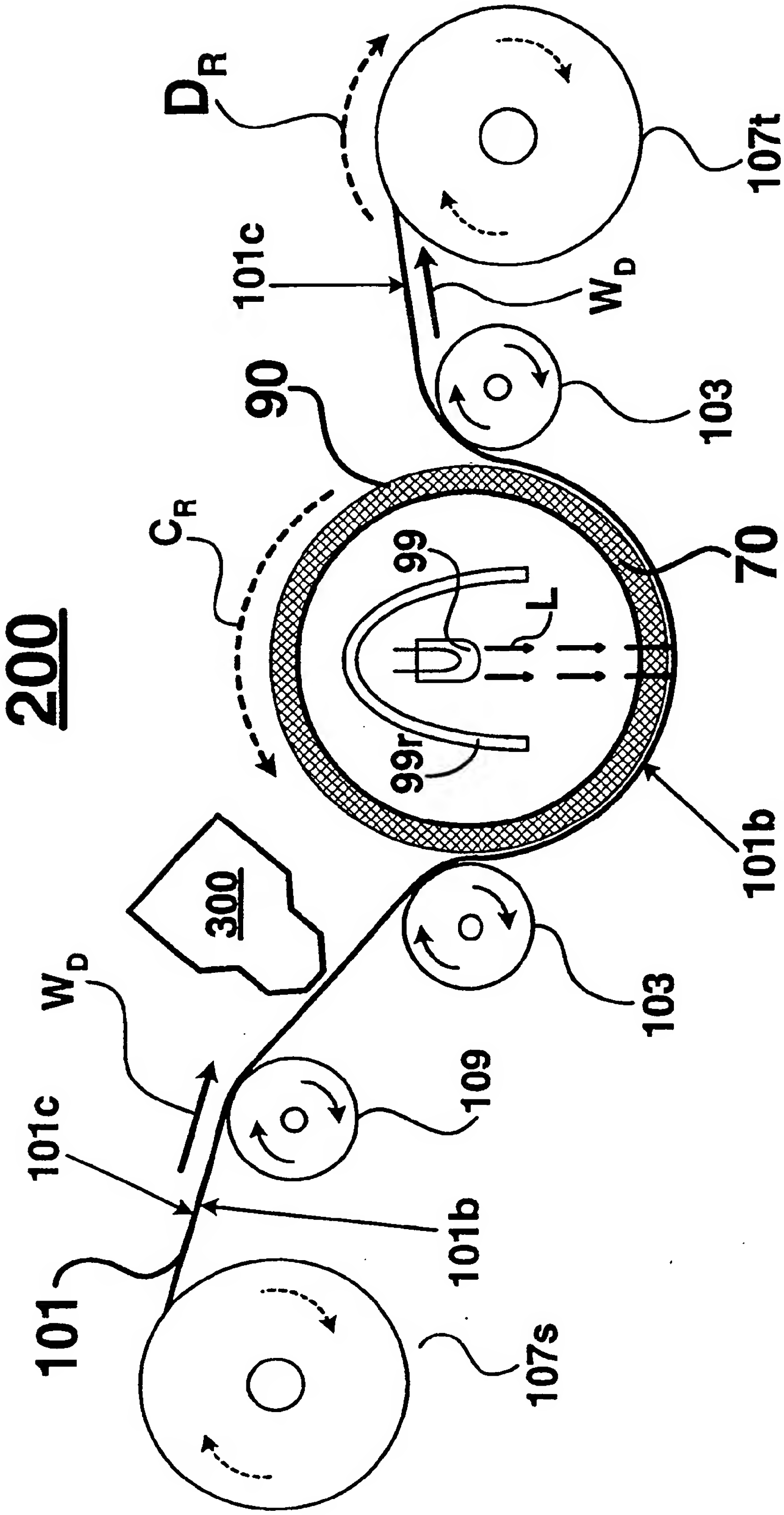
200
300
101
101c
101b
W_D
109
103
C_R
99
99r
L
70
90
101b
103
101c
W_D
D_R
107s
107t

FIG. 41

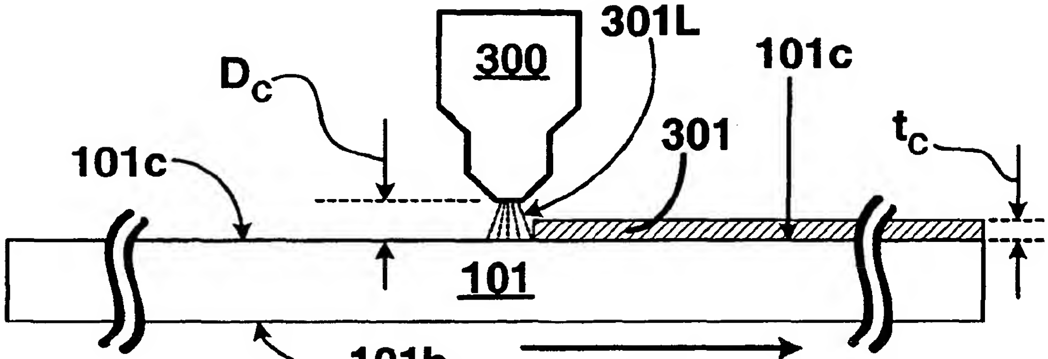

FIG. 42

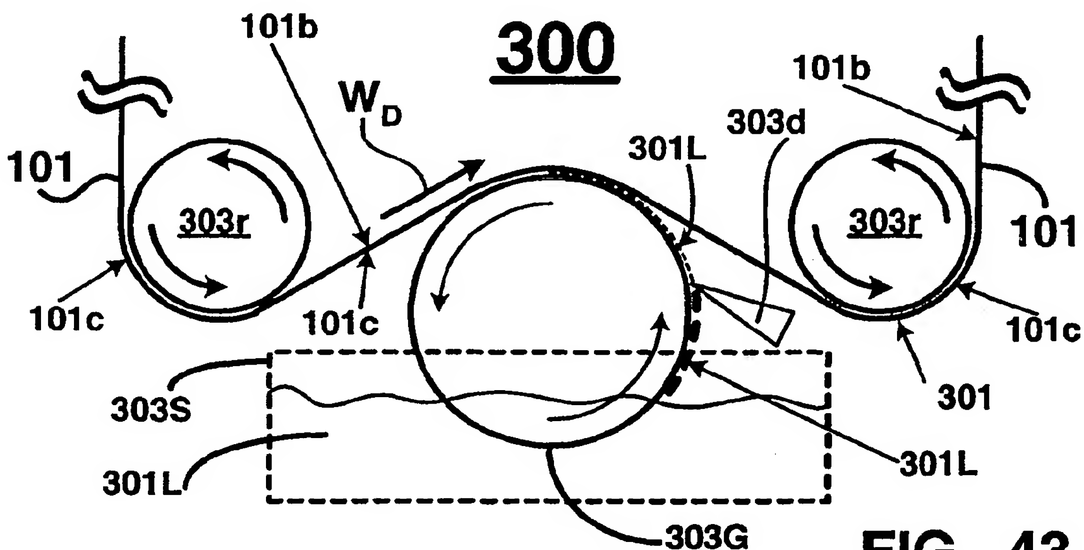

FIG. 43

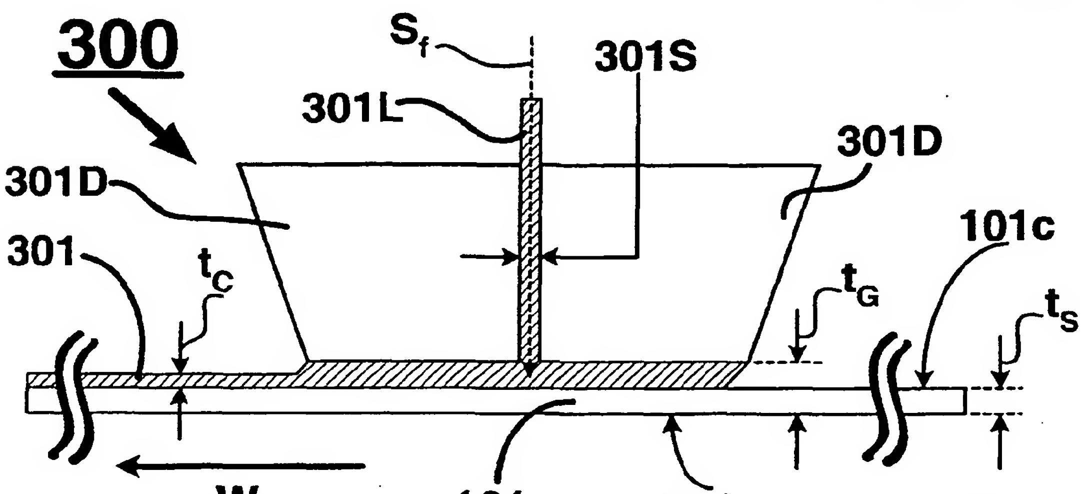

FIG. 44

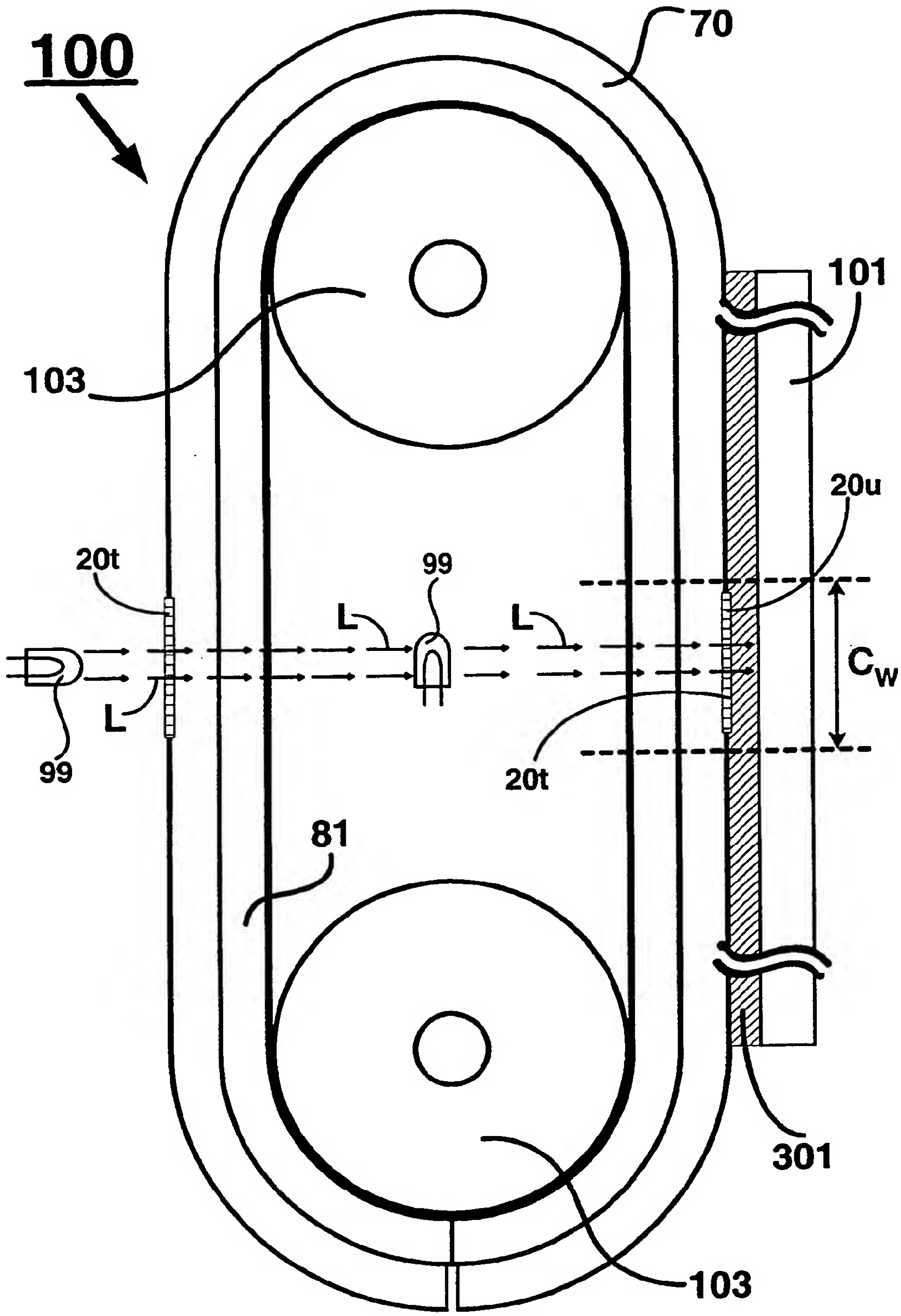

FIG. 45

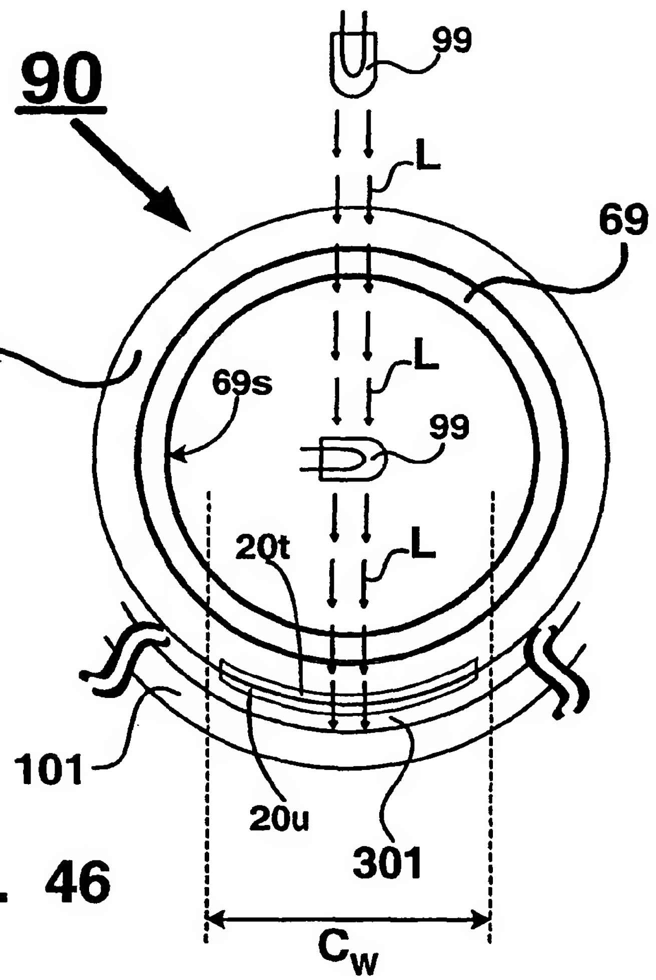
90
99
L
69
70
69s
L
99
20t
L
101
20u
301
C_W

FIG. 46

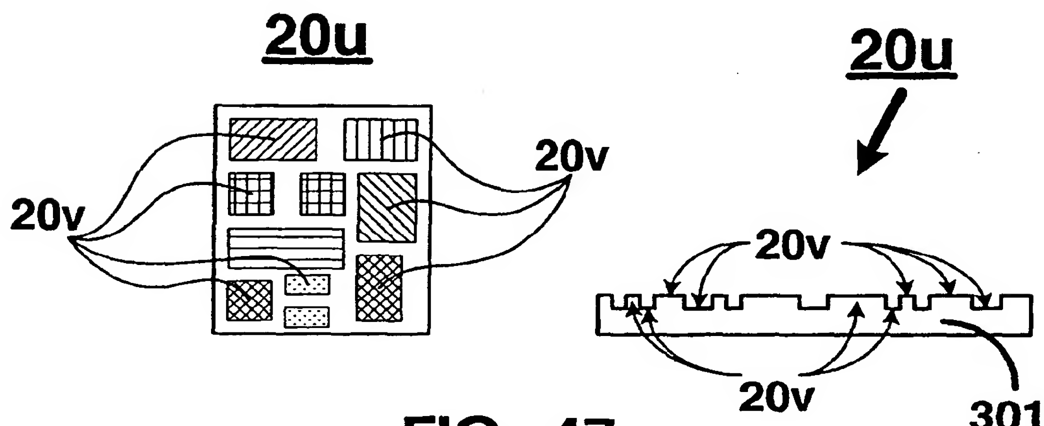
20u
20v
20v
20u
20v
20v
301

FIG. 47